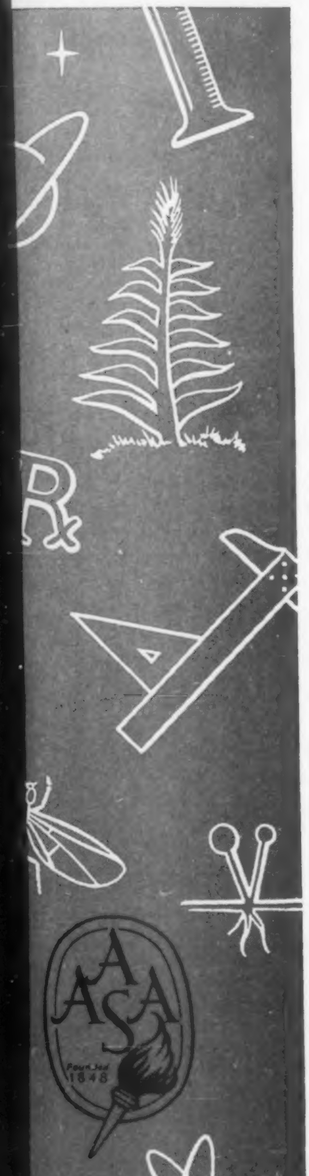
SCIENCE

JANUARY 1, 1954

VOLUME 119 NUMBER 3079



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AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

Medical

Public Reaction to Nonmilitary Aspects of Atomic Energy

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ANY EFFORT TO DISCUSS or analyze public reaction to peacetime uses of atomic energy is severely limited by the paucity of empirical research available. Kay and Gitlin have pointed out that of all survey questions devoted to the area of atomic energy, small indeed has been the number inquiring into opinions and attitudes on peaceful applications. At the time of their review of questions used by national polling organizations (1948), war-related questions outweighed those oriented toward peaceful applications by approximately 18 to 1 (*1*).

This distribution of question content is revealing. The emphasis on the atomic bomb and other weapons cannot be narrowly attributed to the interests or aggressive needs of pollers. It reflects an accent detectable in our entire society—in the press and other communication channels, in budget allocations, in statements of government leaders and other official pronouncements, and in the discussions of laymen. Where atomic energy is concerned, the bomb is central. This fact is not surprising. Born in war, the field of atomic energy has grown up in times of troubled peace. Research and development emphasis, consequently, has concentrated on weapons. No peaceful use of nuclear power has approached the drama and significance of the bomb.

However, it is important to assess the public response to the less publicized peaceful aspects of atomic energy. Hopefully, we may predict that man will arrive at some means by which to handle, albeit precariously, the threat implicit in the development. In this event its other side, the constructive side, will move upstage and will demand certain unique societal adjustments. The successful introduction of any new technological development depends in some measure on the receptivity of the public and special groups. It is important then to gather our limited data on public thinking about nonmilitary uses of atomic energy and attempt to draw from them an understanding of how the population at large reacts to this phenomenon.

What we have learned relates to two distinct but interrelated questions:

What is the state of public thinking about the broad discovery of atomic energy and its nonmilitary uses? What are some of the factors which account for a pessimistic negative evaluation of atomic energy by a sizable minority of the population?

Public Thinking About Atomic Energy

In assessing popular thinking about a new phenomenon, there are a number of facets to be considered. These may be phrased as a series of questions: How much do people know about the topic? How interested are they in it? Do they feel generally optimistic or pessimistic about it, that is, do they evaluate it positively or negatively?

The study from which the findings in this section of our report are drawn had as a major objective the comparison of attitudes in atomic installation communities with attitudes found in similar noninstallation communities (*2*). The sample required for this purpose is at most representative of Americans living in small and middle-sized cities. Since, however, it includes individuals geographically proximate to atomic energy plants, it seems reasonable to assume that this group should have at least as much information about the topic as a cross-section sample of the nation.

It is not surprising, in view of the relatively modest and specialized peacetime developments of atomic energy, that available data reveal the lay population to be ill-informed about atomic energy apart from the atomic bomb. About two-thirds of the people interviewed reported having heard of atomic energy in connection with something other than the bomb, but their knowledge was fragmentary. One person in five either "denied any impression that there were other uses than the bomb (or) did not report the vaguest concept of even general areas in which atomic energy could be used in peacetime" (*3*).

Among the two-thirds who knew of some nonmilitary use, very few mentioned more than one application. The most frequent was power, a characteristic quite readily associated with its military use. This application took various forms, however, sometimes alluded to as a source of power or energy, sometimes as a source of heat, or as fuel and motive power. Almost three-quarters of the group reported knowledge of this use. Medical purposes were mentioned with secondary frequency. About one-half alluded to them. Minor emphasis, less than one-tenth in each case, was given to agricultural, industrial, and scientific uses of atomic energy.

In answer to a question regarding what atomic energy is or what it is like, about one person in fourteen was able to give an informed response. Almost half the respondents said simply that they did not know (*4*).

In summarizing the section of their investigation dealing with information, the authors of this study concluded (*5*):

> The field of atomic energy seemed to exist as bits of information, varying interests and reactions that related to one or another specific uses, problems, or policies. It clearly did not exist as a rather well-structured phenomenon that fitted within a relatively well-defined area of interest for the overwhelming number of . . . respondents (*5*).

Nor does there seem to be much hope that this population will gain additional information about atomic energy or peaceful uses in the near future. Half of the respondents answered negatively when asked "Do you think that the average individual can understand enough about atomic energy to make it worth while to read things about it?" (*6*).

The amount of knowledge people have about a subject is indirectly a measure of the amount of interest the subject holds for them, since information-seeking demands interest. Having observed that people have very meager knowledge of nondestructive atomic developments, we might expect to find that they are also relatively uninterested in these developments. This is, in fact, what the survey results disclose.

Half of the respondents in this study reported feeling indifferent toward information about atomic energy when they came across it in their reading (*7*). Only about 10 per cent reported discussing atomic energy with family or friends more than "once in a while." Half said they rarely or never did (*8*). When asked whether there was anything about the subject they wondered about (in addition to information they already had), about half of those questioned were "disinterested in further data about atomic energy." Only one in six respondents both wanted more information and had some notion of where it might be obtained (an indication of at least minimal action resulting from the stated interest) (*9*).

From these findings it does not appear that the development of atomic energy and the allegedly revolutionary social and economic changes which it portends have captured the imagination or stimulated the curiosity of the majority of the lay population. The authors of this study found that "at this time involvement with the atomic energy process is restricted to the upper socio-economic and relatively well-educated groups in the population" (*10*). They conclude that nonmilitary aspects of atomic energy have not been made salient or meaningful for the bulk of the population because they have not been tied in any way to their own interests. This conclusion was equally applicable to residents of installation and noninstallation areas and indicates that the lack of salience of the subject of atomic energy is not simply a matter of geographical distance from the development.

What are the attitudes of people toward the development of atomic energy? Despite their lack of information and personal interest in the peaceful applications of atomic energy, it is encouraging to find that most people recognize, at least superficially, the potential importance of the field, and that they are generally optimistic about the eventual good which it will produce.

When asked "How important do you think it will be for those young people (of high school age) to understand atomic energy?" some 75 percent of the respondents revealed that they consider atomic energy to be of significance for coming generations (*11*). Nearly 60 percent thought that, "considering all its uses in peace and war," we will be better off for having discovered atomic energy. Only about one person in five was definitely negative about the development, with the remaining group uncertain or neutral in their reactions (*12*).

We are now in a position to give a tentative answer to the first of the two questions asked at the beginning of this article: What is the state of public thinking about the broad discovery of atomic energy and about its peacetime uses? We have seen that laymen are in general uninformed and uninterested in the development, but that nevertheless most people are optimistic and have generally positive feelings about it.

The Pessimistic Evaluation of Atomic Energy

The question remaining is: What factors account for negative or hostile reactions to the development, where they *do* occur? The importance of this question is not diminished by the fact that the majority of respondents are hopeful and positive in their evaluations. The proportion of respondents who hold a pessimistic view is still sizable. Understanding the basis for such a reaction may aid us in counteracting it or in preventing its spread.

A recent survey, sponsored by the Phoenix Memorial Fund of the University of Michigan, yielded some information relevant to this problem (*13*). In this study a representative sample of the Detroit labor force was questioned about atomic energy, in addition to other things. Among the questions asked was the same general evaluation question referred to in the previous discussion. People were asked to consider both wartime and peacetime uses of atomic energy, and to judge, in this context, whether we have gained or lost by the discovery. Again a majority felt positive toward atomic energy, and a minority felt that we would have been better off had it not been discovered.

An effort was made to establish factors that differentiate these two groups, and certain significant findings appeared.

The most important difference appeared in a variable termed "feeling of effectiveness." Negative reactions to atomic energy were most frequently given by people who were characterized by a feeling of powerlessness in public affairs. Confronted with the issue of atomic energy, with its threatening as well as con-

structive potential, they felt unable to handle the threat or even to contribute to its solution. Feeling unable to face the danger implicit in atomic developments, they tended to turn away from the entire field. They had fewer ideas about the topic than more effective people, and they were more likely to withdraw from the topic and wish that atomic energy had never been invented.

People who evaluated atomic energy positively, on the other hand, were marked by a high degree of psychological effectiveness. In response to questions about atomic warfare, they gave mainly two kinds of response. Either they recognized the danger but felt that something could be done about it, or they felt that there was no danger of atomic war and gave relatively well-thought-out and logical rationales for this judgment (indicating that they had faced the threat, but had concluded that it was not as great as originally conceived). In both cases, the danger was handled in a relatively realistic manner. These people were able, then, to look beyond the bomb to some of the constructive possibilities of atomic energy. Unimpeded by disorganizing fear, they were able to evaluate the discovery as a useful step in man's progress.

It was found, further, that there was a significant relationship between a feeling of effectiveness in public affairs and security feelings with respect to one's personal life. Those who were able to deal realistically with public affairs were also likely to feel satisfied with their own lives, confident about the future, and in control of their own futures. Ineffective people were likely to feel less in control and less optimistic concerning their day-to-day lives.

Two conclusions seem justified by these findings. The first has to do with the spread of nonreceptive, negative attitudes toward new atomic innovations. Since it appears that those who hold such attitudes are something like chronic pessimists, we may suggest that atomic energy is not creating unique negative reactions. People who are ordinarily secure and confident are not suddenly given to defeatism and fearful antiprogress sentiments when atomic energy is introduced. This means that a rapid spread of negative attitudes is not a probable danger.

The second conclusion relates to the problem of counteracting pessimism and nonreceptive attitudes where they do exist. The frightened people who hold such a position are relatively unable to distinguish between the good and the destructive sides of atomic energy. In helpless fear of the threat aspect, they confound the two sides and wish to undo the entire development. Presumably, if the threat of atomic war subsides in the world, these people will be able to look at atomic energy more realistically and will be more receptive to new innovations. Meanwhile, educational steps can be taken to help them differentiate more clearly between peacetime and military uses. Emphasizing constructive applications and clarifying their relation to the interests and experiences of the average person might go a long way toward building support for the new field and even toward helping ineffective people to place the danger elements themselves in a more realistic perspective. If it becomes clearer that good will be achieved by atomic energy, it may help this group to face the threat itself as a necessary condition for obtaining equally large benefits.

To summarize, the development of atomic energy, up to this point, has been tied largely to wartime needs and military demands. Peaceful applications have been comparatively modest and exceedingly specialized. Their consequences have not directly entered the life of the average citizen. His automobile is not run by atomic power; atomic power has not changed his job, his diet, his house, or his recreation.

In view of this lack of immediacy, it is not surprising to find that most people know very little about atomic energy and its peaceful uses. Even their lack of personal interest in the subject is more understandable when we consider this unreality. In addition, the public has not had access to much information. The press and other communication media have played up, for obvious reasons, the drama of the bomb rather than the less spectacular peacetime applications of atomic energy.

We often expect that events that are unknown and outside the mainstream of people's interests, if they are also major innovations, may be somewhat awesome and even frightening to people. While there is some indication that people are awed by the technical nature of atomic energy, there is relatively little indication that they are fearful and negative about it. A substantial majority is able to handle the danger implicit in atomic energy and feels optimistic about peacetime uses.

In cases where individuals are fearful and negative, their reactions appear to stem from personal insecurity rather than from the unique impact of atomic energy. Depending, as it appears to do, on elements of individual inadequacy, this pessimism toward the development is not likely to spread quickly through the general population. Also, there is some hope that the attitudes of the negative minority can be influenced by effective educational efforts emphasizing the constructive aspects of atomic energy.

References

1. KAY, L. W., and GITLIN, I. J. *J. Social Psychol.* **29**, 57 (1949).
2. FISHER, B. R., METZNER, C. A. and DARSKY, B. J. *Peacetime Uses of Atomic Energy*, Vols. I and II. Ann Arbor: Survey Research Center, University of Michigan, 1951.
3. ———. *Ibid.*, Vol. I, p. 36.
4. ———. *Ibid.*, p. 37.
5. ———. *Ibid.*, p. 26.
6. ———. *Ibid.*, p. 97.
7. ———. *Ibid.*, p. 86.
8. ———. *Ibid.*, p. 66.
9. ———. *Ibid.*, p. 69.
10. ———. *Ibid.*, Vol. II, p. 80.
11. ———. *Ibid.*, Vol. I, p. 70.
12. ———. *Ibid.*, p. 87.
13. *The Impact of Atomic Energy on Society*, mimeograph report, Survey Research Center, University of Michigan, 1953.

Metals for Reactor-Core Construction[1]

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WITH THE ADVENT of the atomic energy program, the materials engineer was faced with many new and trying problems. A new criterion, that of nuclear properties, was added to the usual consideration of physical and chemical properties. Frequently the materials engineer found that nuclear properties overruled all other considerations, even cost. This new concept plagued him even in unexpected cases. He found that items such as steel which were normally considered stock items sometimes contained traces of boron and other high-cross-section elements. No material could be accepted at face value.

As the program developed, it was found that most of the materials which could be used in atomic energy applications were either extremely rare or had to be in a highly purified state. To grasp the problem that faced the materials engineer, let us consider the state of development in 1940. Uranium was a laboratory curiosity. Some of its ores had been mined primarily to obtain the radium that occurred with it. Very small quantities of metal of questionable purity were being produced by either the reduction of the oxide or fused-salt electrolysis. The situation on thorium was a little better as considerable quantities of oxide had been produced for gas mantles and small quantities of metal had been produced. The processes in use, however, were far from adequate for large-scale production of high-purity material. Beryllium and zirconium had been produced in various degrees of purity but in very limited quantities.

It is obvious that remarkable developments have been made in the field of reactor materials during the past ten years. In discussing the status of various reactor materials, it is desirable that they be broken down into classes. For this presentation, I would choose to divide them by their function in a reactor. The classifications are fuels, cladding and structural materials, moderators, and control materials.

The fuel or fissionable material is essential to the operation of a reactor. For our purposes, we will consider uranium, thorium, and plutonium as fuels. In the strict sense, thorium is not a fuel, per se, but is included since it can be converted to a fissionable material.

Uranium is the basic fuel material for reactors. Any reactor must contain either one of the fissionable isotopes of uranium, or plutonium, which is itself made from uranium. Although uranium has been considered extremely rare, it does make up 0.0004 percent of the earth's crust. This is more than such metals as cadmium, bismuth, mercury, and silver, which are not considered rare. Uranium is found in various types of rock as a great variety of minerals. The highest concentrations occur in igneous rocks; sedimentary rocks (sandstones) contain about half as much. Uranium has been found in sea water, river water, and in living organisms. Pitchblende is the richest uranium mineral, whereas the major production comes from carnotite or roscoelite. The uranium content of these latter minerals is usually quite low.

Through a variety of chemical treatments, the uranium-bearing minerals are extracted and purified to produce a high-purity uranium trioxide. Uranium metal has been prepared by several methods. In 1789, Klaproth reduced UO_3 with carbon, obtaining what was then considered to be uranium metal. Peligot showed in 1840 that Klaproth's product was UO_2 and succeeded in preparing the metal by the reduction of UCl_4 with potassium. A number of investigators produced small quantities of uranium metal powder on a laboratory scale by four methods: (1) reduction of uranium oxide with carbon; (2) reduction of uranium oxides with aluminum, calcium, or magnesium; (3) reduction of uranium halides with alkali metals or alkaline earth metals; and (4) electrolysis of uranium halides.

More recently, efforts have been concentrated on the reduction of oxide or halides with the alkali metals, or the electrolysis of uranium halides. Uranium powder of a high degree of purity is produced rather easily by treating uranium metal with hydrogen at about 450° F to form the hydride. This hydride is then decomposed by heating in vacuum at around 900° F.

Since the uranium produced by any of the methods is not in the proper massive shape for fabrication, it was necessary to develop methods for melting and casting into conventional ingots. This problem was made more difficult by the high chemical reactivity of uranium with the atmosphere and with most ceramic crucibles. Considerable effort was expended in the development of furnaces which would permit the melting and casting of uranium without its being in contact with the atmosphere. The solution of the crucible problem also required much work.

In general, uranium is a reasonably well-behaved metal. It can be forged, rolled, swaged, or drawn into any number of shapes including plates, rods, tubes, wire, and thin foils. The only problem in its fabrication is caused by its chemical activity with the atmosphere. This makes it necessary to heat the metal in a protective atmosphere. The chemical activity of

[1] Based on a talk given at the 1953 Conference on Nuclear Engineering at Berkeley, Calif., Sept. 9–11, 1953.

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uranium makes joining of uranium by welding or brazing troublesome but not impossible. Here again the use of vacuum or protective atmospheres during heating is helpful. Uranium is only moderately difficult to machine. The chief problem lies in its chemical activity. Proper lubricants and coolants are needed to prevent excessive burning of the metal. As might be expected, the corrosion resistance of uranium in most media including air and water is very poor. This has led to considerable interest in protective coating by electroplating or other techniques. A large number of metals can be plated on uranium from conventional plating baths.

Considerable work has been done on the physical and chemical properties of uranium. Some of the important data are shown in Table 1. Frequently, the physical and chemical properties of a metal can be improved by alloying. In the case of an enriched reactor fuel, it is also advantageous to make use of an alloy to dilute the concentration of the fuel. For these reasons, a large number of uranium-alloy systems have been investigated. As one might expect, a number of types of constitutional diagrams are encountered. In Fig. 1 is shown the uranium-aluminum system. It is quite complicated and has several compounds. Similar systems are developed with beryllium, bismuth,

TABLE 1. Properties of uranium.

Density near 20° C, g/cm³		19.1	
Melting point, °C		1133	
Boiling point, °C		3900	
Specific heat near 20° C, cal/g °C		0.028	
Coefficient of linear thermal expansion, 10^{-6} per °C			
Direction parallel to axis			
	25°–125° C	25°–325° C	25°–650° C
a	21.7	26.5	36.7
b	− 1.5	− 2.4	− 9.3
c	23.2	23.9	34.2
Volume coefficient	45.8	48.6	61.5
Thermal conductivity near 20° C, cal/sec cm °C			0.060
Electrical resistivity, microhm-cm—25–50 (25° C)			
Allotropic transformations, °C			
Heating	α–β	663	
	β–γ	764	
Cooling	γ–β	762	
	β–α	660	
Crystal structure			
alpha, orthorhombic			
beta, tetragonal			
gamma, body-centered cubic			

Average Tensile Properties of Alpha-Rolled, Alpha-Annealed Material

Test temp., °F	Yield strength (0.2% offset), psi	Ultimate strength, psi	Elongation, %
Room	25,000	90,000	13.5
570	18,000	32,000	43.0
930	6000	10,000	57.0

Young's modulus, psi 30×10^{-6}

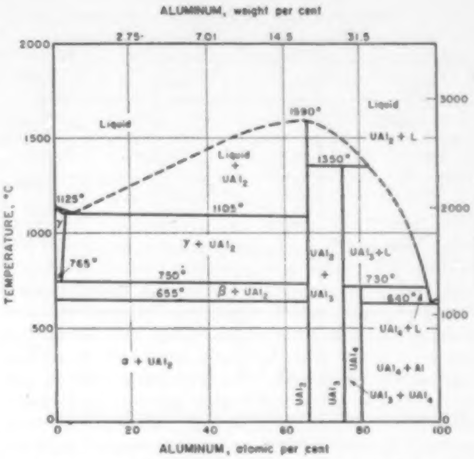

FIG. 1. Uranium-aluminum constitutional diagram.

carbon, cobalt, copper, iron, lead, manganese, mercury, nickel, oxygen, silicon, and tin. In Fig. 2, the uranium-vanadium system, we have the other extreme, a simple eutectic system with little solid solubility. Chromium forms a similar system. Molybdenum, niobium, titanium, and zirconium show extensive solid solubility at elevated temperatures and contain no true compounds. Tantalum and tungsten form a peritectic-type system, whereas thorium forms a monotectic.

Thorium is considered as a secondary reactor fuel since it will, during irradiation, absorb a neutron and become U^{233} which is in itself fissionable. By this mechanism known as breeding, we might be able to increase our supply of nuclear fuel. Thorium is found principally as the oxide in monazite sand. Chemical methods similar to those employed for uranium are used to prepare high-purity oxides or halides of thorium. These compounds are reduced to metal by the techniques previously described for uranium. For some special purposes requiring high-purity metal, the deBoer iodide process has been used. In this process, thorium tetraiodide is thermally decomposed on a heated filament. The process is carried out inside a sealed tube. The product is a loosely knit crystalline product which is then arc melted. The melting of thorium, like uranium, has offered considerable difficulty. The higher melting point of thorium has made the crucible problem even more difficult.

Thorium fabricates very well. It can be worked by a variety of methods either hot or cold. It is very ductile and permits large reductions before requiring annealing. Thorium has been forged, rolled, swaged, extruded, and drawn to produce rods, sheet, thin-walled tubes, fine wire, and thin foils. Again the chemical activity of the metal dictates heating in a protective atmosphere or salt bath. Welding of thorium has been only partly successful. In addition to the atmosphere problem, the metal seems to be sensitive to small

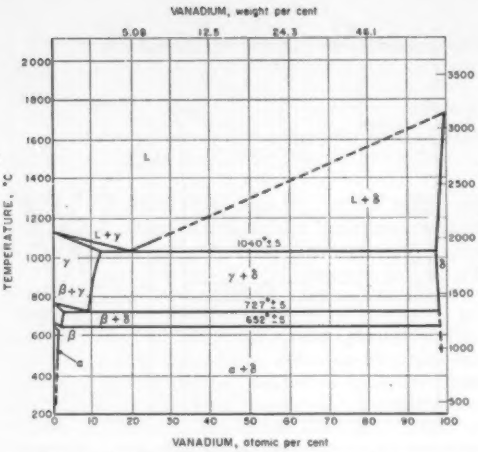

FIG. 2. Uranium-vanadium constitutional diagram.

amounts of impurities. Furnace brazes, when they have been produced, are brittle and unreliable. The machining characteristics of thorium are similar to those for mild steel. Coolants are desirable but not essential. Thorium, like uranium, has poor corrosion resistance. In general, it is somewhat better than uranium. Protective coatings are desirable and can be obtained easily by electroplating. Data on the physical and chemical properties of thorium are given in Table 2.

Because uranium and thorium are neither corrosion resistant nor very strong, it is necessary that another metal be used either for cladding or support. The same metal is likely to be used as the principal structural material for the reactor core. In addition to the usual requirements of structural materials, such as adequate strength, fabricability, thermal stability, and satisfactory corrosion resistance, we must add nuclear properties.

The number of metals suitable for structural use in thermal reactors is severely limited since only aluminum, beryllium, magnesium, and zirconium have thermal-neutron-capture cross sections of less than 0.5 barn/atom. Of these metals, aluminum and magnesium are certainly well-known commercial metals, and their production and fabrication warrants no further discussion. Beryllium and zirconium, both considered rare and exotic, deserve some consideration of their production techniques.

Beryllium is a very light white metal which has become well known for its toxicity and unexplained poor ductility. Its high melting point, low capture cross section, and good moderating qualities make it a promising reactor material. These are offset by poor ductility, erratic corrosion resistance, and considerations of health. Although beryllium exists in approximately thirty minerals, only one is of commercial importance. This is beryl, a beryllium aluminum silicate which usually contains from 8 to 14 percent of beryllia. The beryl ore is treated chemically to produce beryllium fluoride. This is then reduced to metal by either calcium or magnesium.

The product of the reduction process is a pebble or lump which must be reprocessed for further fabrication. It can be vacuum melted to form massive ingots or treated to form powder. The melting and casting of beryllium have not been completely satisfactory. The ingots produced are likely to contain nonmetallic impurities and do not produce good finished shapes. Powder metallurgy has been developed to such a point that most of the billets for further fabrication are produced by this method.

Beryllium does not fabricate easily. It has been extruded to form various shapes. Hot forging and rolling are usually done in a steel jacket. Cold working is difficult. In spite of its poor fabricability, a rather large number of shapes have been produced. Beryllium can be joined by either welding or brazing. The techniques are complicated by the rapid oxidation of the metal in the atmosphere. The machining of beryllium is made difficult by its tendency to surface damage. Cracking can occur below the surface unless great care is exercised. The corrosion resistance of beryllium in air and water is poor. It is not as bad as uranium or thorium, however. Considerable effort has been placed on electroplating. Once the surface has been chemically cleaned, plating with copper, nickel, zinc, tin, iron, or silver is quite feasible.

At the present time, zirconium with its low thermal cross section, excellent corrosion resistance, good mechanical properties, and good fabricating qualities is the leading cladding and structural material for thermal reactors. It is interesting to note that zirconium has not always been regarded so favorably. All zirconium ores contain small amounts (0.5–3%) of hafnium which is not removed during ordinary production of the metal. The high cross section of hafnium caused the values for zirconium to appear high also. It was only after a sample of pure zirconium was prepared that its low cross section was demonstrated and a great

TABLE 2. Properties of thorium.

Density near 20° C, g/cm³	11.71
Melting point, °C	1690
Boiling point, °C	> 3000
Specific heat near 20° C, cal/g °C	0.028
Coefficient of linear thermal expansion near 20° C, 10^{-6} per °C	11.15
Thermal conductivity near 20° C, cal/sec cm °C	0.09
Electrical resistivity, microhm-cm	18
Crystal structure, face-centered cubic	

Average Tensile Properties of Alpha-Rolled, Alpha-Annealed Stock

Test temp., °F	Yield strength (0.2% offset), psi	Ultimate strength, psi	Elongation, %	Young's modulus, 10^6 psi
Room	27,000	37,500	40	10
570	12,000	22,000	38	8
930	9500	17,000	50	7

TABLE 3. Physical and chemical constants of aluminum, beryllium, magnesium, and zirconium.

Property	Aluminum	Beryllium	Magnesium	Zirconium
Thermal-neutron-absorption cross section, barns/atom	0.215	0.009	0.059	0.18
Density near 20° C, g/cm³	2.699	1.85	1.74	6.5
Melting point, °C	600	1315	650	1845
Boiling point, °C	2327	2970	1120	
Specific heat, cal/g °C	0.215	0.43	0.25	0.069
Coefficient of linear thermal expansion, 10^{-6} per °C	23.8	11.6	26	5
Thermal conductivity, cal/sec cm °C	0.50	0.38	0.38	0.057
Electrical resistivity, microhm-cm	2.655	5.9	4.46	41
Crystal structure	FCC	CPH	CPH	CPH

boom in popularity was started for this once rare metal.

Zirconium occurs in a number of minerals which are widespread over the earth. The principal commercial sources of zirconium are zircon ($ZrSiO_4$), zircite (ZrO_2), and baddeleyite (ZrO_2). All ores contain hafnium, generally in amounts from ½ to 3 weight percent, but some contain as much as 20 weight percent. The principal problem in the production of zirconium metal is the hafnium removal. After much effort, several methods have been developed that produce a high-purity low-hafnium oxide. To produce metal, the oxide is chlorinated either with CCl_4 or by mixing with carbon, pelletizing, and treating with chlorine at elevated temperatures. The chloride is purified by distillation and reduced by magnesium. The product is a slightly porous sponge.

Sponge zirconium can be further refined, using the deBoer iodide process. In this process the sponge is converted to zirconium tetraiodide, which is then thermally decomposed on a heated zirconium filament. This operation removes oxygen, nitrogen, and magnesium. As the quality of zirconium sponge has improved, more emphasis has been placed on direct melting and casting. A high degree of chemical activity again rules out conventional melting methods. Two methods, vacuum-induction melting in a graphite crucible and arc melting in a water-cooled copper crucible are used successfully. For some time, induction melting was preferred. The high carbon content of such metal has led to development of better arc melting techniques. Arc melting is now the leading method. For arc melting, the sponge is pressed to form square bars which serve as the consumable electrode. The metal is melted in a direct-current arc which is maintained between the electrode and the molten bath. The molten bath is contained in a water-cooled copper crucible.

Zirconium is very ductile and can be fabricated easily. All conventional fabrication methods are used to produce a wide variety of shapes. Some precautions are necessary because of the moderately rapid oxidation. For shapes which are to be machined to final size, there is no problem. Material which is to be fabricated to close tolerances should be protected by an inert atmosphere or by jacketing. The same precautions are required during annealing. Zirconium welds easily in a good protective atmosphere. A heliarc torch operated in a helium-filled chamber works well. Brazing is made difficult by the fact that brittle compounds are formed between zirconium and the common brazing metals. Machining characteristics of zirconium resemble those of aluminum. Zirconium is very soft and ductile and galls readily with materials rubbed against it. For some applications it would be desirable to coat zirconium with thin layers of another metal. Electroplating with either nickel or iron is possible. In either case, the electroplate must be diffusion annealed to promote adherence. Properties of the four leading structural materials for thermal reactors are given in Tables 3 and 4.

A great many more structural or cladding materials become available if a higher cross section can be tolerated. Pure metals include niobium, iron, molybdenum, chromium, copper, nickel, vanadium, and titanium. A number of alloys such as stainless steel or Inconel are available in the intermediate cross section range. Moderating materials for thermal reactors should be capable of reducing neutron energy rapidly. This requires a low atomic weight. Good moderators have a high scattering cross section and a low absorption cross section for thermal neutrons. The only good solid moderators are beryllium, beryllia, and graphite. Beryllium has been discussed in detail as a structural material. In spite of many shortcomings, beryllium and beryllia have been used as moderators. Graphite has found widespread use as a moderator because it is cheap, abundant, easy to work, and has good physical properties.

Materials for control must possess high cross section for the absorption of neutrons. They should also have some strength, be fabricable, and have reasonable corrosion resistance in the reactor coolant. Of the material elements, boron and cadmium meet most of these requirements and have been used extensively. Hafnium, with its high cross section and metallurgical properties similar to zirconium, should make an excellent control material. Some of the rare earths have very high cross sections but have not been available in sufficient quantities. As they become available, they will no doubt be used either alone or in alloys.

It might be well to consider reactor materials of the future. For fuel, we will still have uranium and thorium with more emphasis on plutonium. In the field of structural materials we are bound to see a number of changes. As power levels increase, operating temperatures also increase. We are fast reaching the point where aluminum is losing out because of lack of strength and corrosion resistance at elevated temperatures. Zirconium can, of course, compete to much

TABLE 4. Tensile properties of aluminum, beryllium, magnesium, and zirconium.

Property	Test temp., °F	Aluminum	Beryllium	Magnesium (Alloy AZ92)*	Zirconium
Yield strength (0.2% offset), psi	Room	5,000	33,000	16,000	18,000
	400	3,000	20,000	13,000	10,000
	600	1,500	15,000	7,000	8,000
Ultimate strength, psi	Room	13,000	80,000	24,000	32,000
	400	6,000	50,000	19,000	20,000
	600	2,500	40,000	9,000	16,000
Elongation, %	Room	45	2	1	25
	400	70	8	9.5	50
	600	90	17	22.5	60
Young's modulus, 10^6 psi	Room	10	40	6.5	13.8
	400	9			11.5
	600	6.5			10.5

* Alloy AZ92 (Mg 9.5Al—2Zn) was selected as typical of the magnesium-rich alloys suitable for reactor application.

higher temperatures. Eventually, for water-cooled reactors, we may have to go to titanium and stainless steel. For gas-cooled reactors, the operating temperatures must be much higher. Stainless steel only begins to meet these requirements both from the viewpoint of strength and oxidation resistance. Molybdenum has adequate strength but low oxidation resistance. Alloys such as iron-chromium-aluminum have adequate oxidation resistance but little strength. For very high temperatures, probably only ceramics have a chance. They do have serious shortcomings in lack of tensile strength and poor thermal-shock resistance. Apparently, the materials engineer will have his problems for many years in the future.

Bibliography

1. KATZ, J. J., and RABINOWITCH, E. *The Chemistry of Uranium*, National Nuclear Energy Series, Division VIII, Vol. 5, New York: McGraw-Hill, Unclassified, 1951.
2. CHIOTTI, P., and ROGERS, B. A. *The Production of Uranium and Thorium in Powder Form*, Ames, Iowa: Iowa State College, ISC-31.
3. CAHN, R. W. *Plastic Deformation of Uranium Atomic Energy Establishment*, Harwell, England: AEUE-M/R-740, 1950.
4. WATHEN, T. *Corrosion of Uranium Metal in Air and Steam at Various Temperatures*, Imperial Chemical Industries, Ltd. (Brit.): BR-223A, May 13, 1943.
5. GORDON, P., and KAUFMANN, A. R. *The Alloy Systems Uranium-Aluminum and Uranium-Iron*, MIT: AECD-2683, August, 1949.
6. BORIE, B. S., JR. "Crystal Structure of UAL_4, Oak Ridge National Laboratory," *J. Metals*, September, 1951.
7. SALLER, H. A., and ROUGH, F. A. "Vanadium-Uranium Constitutional Diagram, Battelle Memorial Institute," *Ibid.*, April, 1953.
8. RODDEN, C. J., and WARF, J. C. "Analytical Chemistry of the Manhattan Project, New Brunswick Laboratory," AECD-2701, January, 1949.
9. REYNOLDS, M. B. "New Elastic Constants of Some Metals, Knolls Atomic Power Laboratory," AECD-3242, KAPL-576, May, 1951.
10. HAMBY, D. E. "Mechanical Properties of Thorium," Proceedings of the Metallurgy and Materials Information Meeting, pp. 292–309, TID-5061, Unclassified, 1951.
11. HAMBY, D. E. "Fabrication of Thorium," Proceedings of the Metallurgy and Materials Information Meeting, pp. 381–388, TID-5061, 1951.
12. REYNOLDS, M. B. "The Elastic Constants of Some Possible Reactor Structural Materials," Proceedings of the Metallurgy and Materials Information Meeting, pp. 321–332, TID-5061, 1951.
13. *Zirconium and Zirconium Alloys*, American Society for Metals, 1953.
14. UDY, M. C., SHAW, H. L., and BOULGER, F. W. *Nucleonics* **2**, No. 5 (1953).
15. *Metals Handbook*, American Society for Metals, 1948.
16. Magnesium, ASM Educational Lecture, American Society for Metals, 1946.

Design and Construction of Water Boiler Neutron Source

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NORTH AMERICAN AVIATION has studied reactors of several types, which have different operative powers in the range 0.1 to 200,000 watts, for operation as research reactors. These types have included designs with homogeneous liquid fuel (water boilers), homogeneous solid fuel (the homogeneous graphite reactor) and heterogeneous solid fuel, water moderated and shielded (the "swimming pool" type reactor).

Recently a natural radioactive material being used as a source of neutrons in research and development work by North American Aviation for the Atomic Energy Commission became depleted. A careful analysis indicated and was later confirmed that a small water boiler reactor would be both a more powerful and more economical source of neutrons. Consequently, a low-powered water boiler neutron source (WBNS) was designed, constructed, and installed at the Company's Downey research and manufacturing facility.

Since this reactor is small, simple, safe, and economical and yet embodies the major components and manufacturing techniques typical of all reactors, a description of its design and construction is thought to be of interest.

In the complete installation prior to placing the final shield wall (Remley, Fig. 2, p. 22), the lower tank is 5 feet in diameter and 6 feet high and contains 2 feet of machined graphite reflector which surrounds a 1 foot spherical fuel and moderator core tank. Attached to the tank are a small mixing tank with valves and connecting piping, a large cylindrical accumulator tank and two neutron detecting ion chambers. The associated control and safety rod system and instrumentation panel are located behind the structure and are not visible. The upper tank is experimental equipment which utilizes the neutrons produced in the reactor. The designed power of the reactor is one watt with a maximum flux density of 4×10^6 neutrons per square centimeter per second.

Figure 1 shows the three major systems of this reactor: safety, fuel, and gas disposal. Higher-powered reactors require a fourth system consisting of cooling equipment for removing the heat generated by nuclear fission. The safety system includes two gravity-powered safety rods, and two control rods. The control rods are positioned according to instrumentation indications and recordings on the control panel. These instruments are in turn fed by signals from the neutron detecting devices located around the reactor tank. The fuel system includes a fuel mixing tank, valves, piping, and the reactor core tank.

A description of the major reactor components follows.

Core and Fuel Handling

The reactor core components are shown in Fig. 2. The fuel is contained in a 12-inch diameter stainless steel sphere made of two spun hemispheres each provided with a small upstanding flange at the joint surface. The design of the core tank is representative of the new problems encountered by the engineer developing nuclear reactor components. Corrosion considerations which may be accentuated by radiolysis indicate that special corrosion-resistant steels may be in order. Pressure and corrosion indicate thick walls. Nuclear considerations indicate either thin walls or use of material which does not offer a large cross section to neutron absorption. The answer may be a thin stainless steel capable of being heat treated to a high tensile strength. However, heat treatment causes scaling which is difficult to clean to the degree necessary in the system. The final compromise which included fabrication and economical requirements was the selection of 1/16-inch 347 stainless steel sheet welded without filler by heliarc. Cooling coils are shown to which a refrigeration system can be added at a later date should the reactor be run at higher powers. The long tube and extra tank is an added safety feature developed by North American Aviation which provide an auxiliary catch basin in the event of a flash run-away. The fuel is retained and slowly returned to the core after the conditions that caused the flash have been rectified. Not shown in the photograph is a tube 1⅛ inches in diameter that runs completely through the sphere. After all the components shown are welded in place, the tank is cleaned thoroughly to remove all foreign material. The flanges of the hemispheres are spot welded together to produce accurate alignment and then fused down in a heliarc butt weld. A final cleaning is then performed in the laboratory using hot nitric acid. The welded core tank is then pressure tested to 300 psi using conventional leak testing methods. To find minute leaks, a vacuum is pumped on the core tank assembly while attached to a mass spectrograph. Helium is then introduced on all welds and if a leak large enough to admit helium is present, the leak detector will indicate and the weld may be repaired. The volume of the core tank is then accurately determined as a function of height (see Fig. 3).

To fill the core tank for operation, the concentrated solution of uranyl nitrate is carefully measured into a vinyl bottle by volume using the burette shown in Fig.

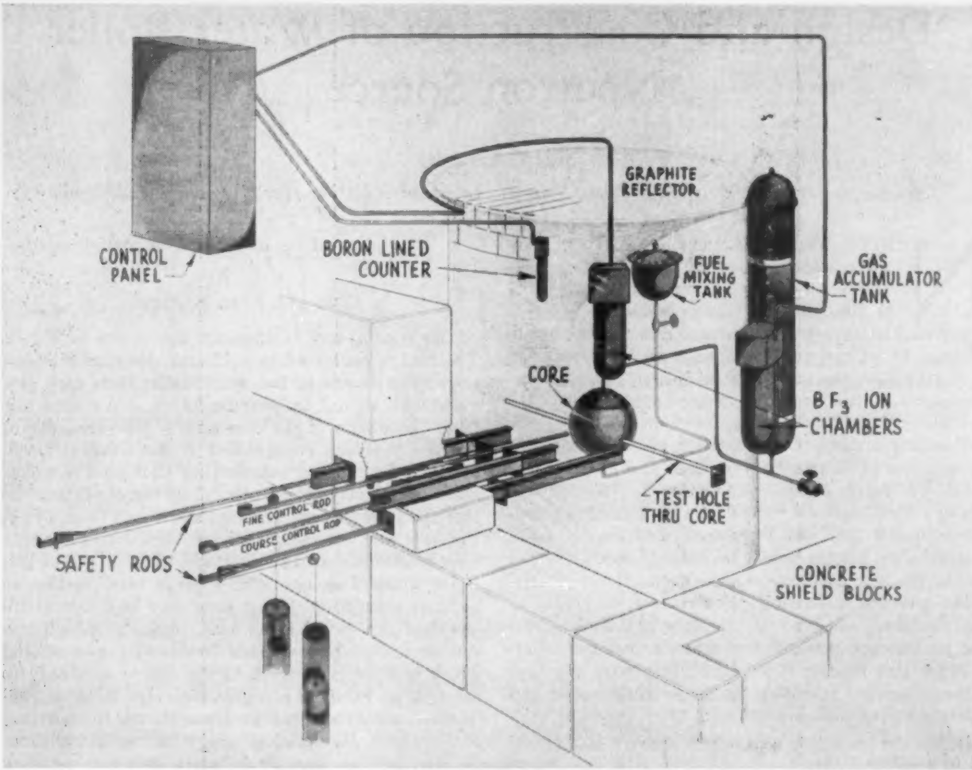

FIG. 1. Three major systems in reactor: (1) gravity-actuated safety rods and remotely controlled powered control rods, instrumentation, and neutron detection instruments; (2) fuel handling and mixing tank, valves, piping, and fuel core tank; (3) gas disposal system with accumulator, gages, and valving.

4. The amount is then checked by weight. Figure 5 shows the fuel being poured from the vinyl bottle into the mixing tank which is made of stainless steel highly polished for cleanliness and fitted with a sealed cover which allows the container to be either pressurized or evacuated. The mixing tank is connected by a plug valve to the tubing leading to the core sphere.

FIG. 2. Components of reactor core tank. Two spun stainless steel hemispheres, cooling coils, emergency overflow tank, and slow return pump.

The fuel handling system is shown in Fig. 6. A loading sequence includes: (1) filling the core tank with the total calculated amount of distilled water; (2) adding the first aliquot of fuel which is one-half that calculated for the critical mass; (3) bubbling the gas through the solution thus mixing the fuel and

FIG. 3. Accurate calibration of volume of sphere as function of height.

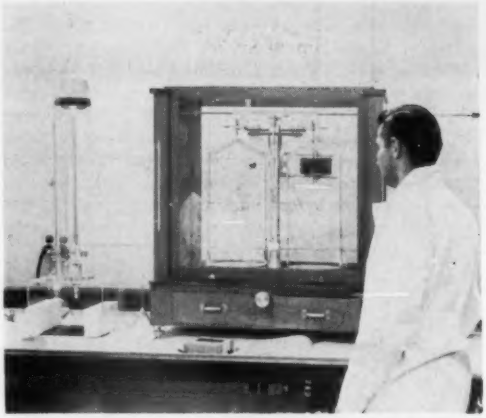

FIG. 4. Apparatus for measuring solution of uranyl nitrate by both volume and weight.

distilled water; (4) raising a portion of the solution into the mixing tank by pressure or vacuum; (5) adding the next measured aliquot which is again one-half the remaining amount to reach the required critical mass; (6) repeating steps 2 through 5 until the reactor is loaded.

During operation of the reactor fission gases are given off as well as hydrogen and oxygen. Since a favorable mixture of H and O might be produced to cause an explosion, the entire system is designed to withstand 300 psi and explosion traps are provided at critical areas. To contain the fission gases at low power operation, calculations had shown that temporary storage and periodic disposal of the accumulated gases would be sufficient. Thus a stainless steel container connected to the top of the core tank was provided (Fig. 6). Inside the container is a Neoprene bag which when pressurized, completely fills the tank expelling all contents as it expands. The pressure connection to the bag passes directly through a packing gland in the top end of the container. Thus, as fission gases are collected in the container, the Neoprene bag is compressed and the rise in pressure indicated on the gage. When sufficient gas has accumulated, the bag is pressurized and the fission gases forced into the disposal tank which can be removed from the system.

For higher-powered reactor operation, the gas generation increases to the point where this system becomes impractical. North American Aviation has recently developed a closed cycle gas handling system which recombines hydrogen and oxygen and processes the fission gases to allow practical disposal of gases at powers up to 50,000 watts.

REFLECTOR

Graphite for the reflector was obtained in rough extrusions about 4½ inches high, 12 inches wide, and 4 feet long. The extrusions were machined on four sides and one end to accurate uniform dimensions

FIG. 5. Pouring measured aliquot of fuel into mixing tank to be mixed with distilled water moderator.

(Fig. 7). The blocks were then selectively assembled so that the layers of graphite were composed of blocks having the same thickness. By this method uniform load distribution was assured. Special care was given to shaping those blocks which were adjacent to the sphere to leave a minimum of air space (Fig. 8). Each layer of blocks was laid with joints in adjacent layers ninety degrees apart (Fig. 9). The principal experimental facility for this reactor is a tank which is placed directly on top of the graphite. The top surface was therefore carefully levelled and kept scrupulously clean by the use of a sealed cover both during

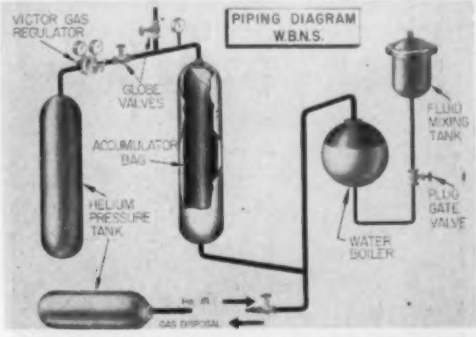

FIG. 6. Schematic diagram of fuel handling and gas disposal system. Fission gases enter stainless steel accumulator tank, compressing Neoprene bag. Gas is disposed of by pressurizing bag forcing gases into disposal tank.

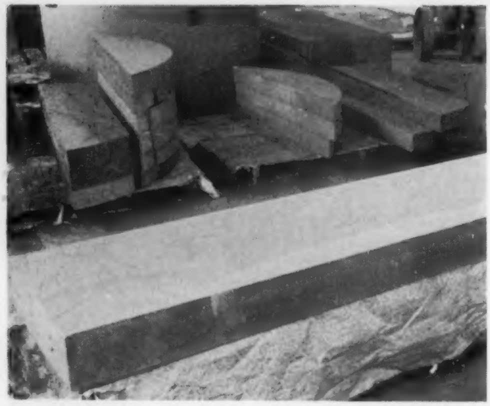

Fig. 7. Extruded reflector graphite to be machined to fit contour of steel tank and reactor core sphere.

the transfer to the laboratory and final assembly.

The tank in which the graphite and core were assembled was made in a structural steel shop and presented no special problems (Fig. 10). The tank bottom was made especially thick to minimize deflection under the graphite load. Openings were provided on the sides

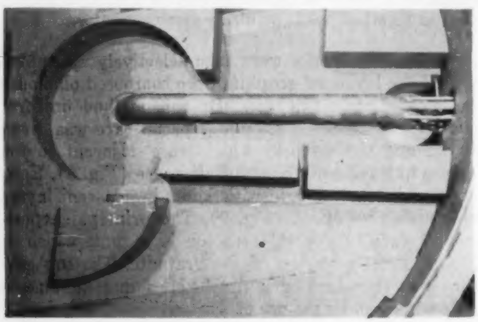

Fig. 8. Machined graphite accurately stacked to fit reactor core components with minimum air gap.

Fig. 9. Layers of reflector graphite stacked with alternate layers at right angles to each other.

to match the locations of control rods and special stringers in the reflector graphite. A strong flange was provided at the top to anchor the experiment tank against movement due to horizontal forces. The graphite tank was mounted on a structural steel base which was furnished with lifting lugs capable of handling the total load of graphite and tank without damage. Leveling screws were incorporated into the base to permit accurate leveling of the assembly on its concrete foundation before anchorage and grouting. Re-

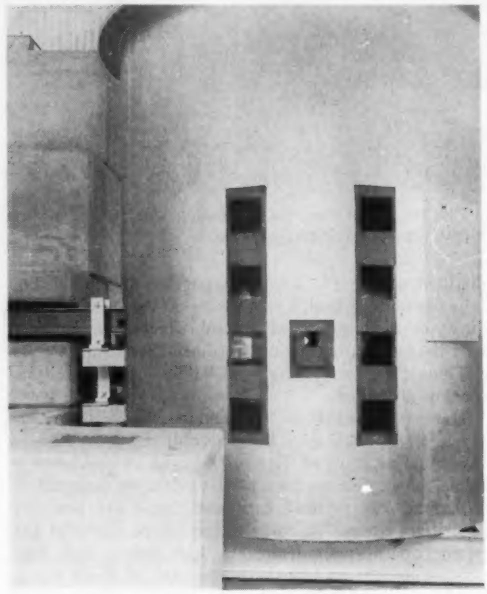

Fig. 10. Experimental facilities include eight removable 4-by-4 inch stringers and 1⅛-inch diameter exposure tube extending through the center of the core and surrounding reflector.

search facilities were provided by removable stringers of graphite and an access hole through the reflector to the exposure hole, permitting maximum irradiation of experimental pieces at the center of the core. The removable stringers are shielded by special removable close tolerance plugs made of wood tipped with lead and cadmium (Fig. 11).

Control

In the control rod system, illustrated in the Remley papers, Fig. 3, p. 23, the two safety rods are held in the "out" position by a trigger mechanism which can be tripped by hand or electrically by remote control at the control panel. Metal counterweights acting under the force of gravity pull the rods to the "in" position to shut down the reactor. When the rods are within 6 inches of their total travel, the counterweights are arrested and wedges on the control rods contact spring-backed brake shoes to absorb the momentum of the rods and stop them before they contact the graph-

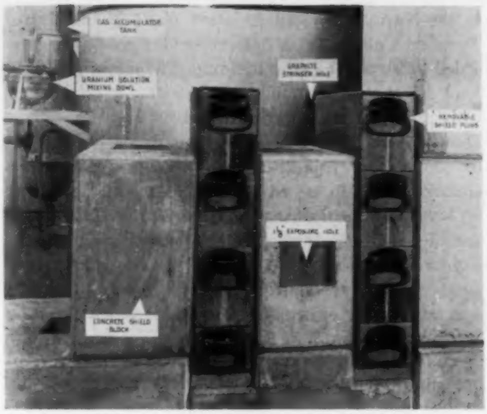

FIG. 11. Removable close tolerance shield plugs for experimental facilities made of wood with lead and cadium tips.

ite in the reflector. The coarse and fine control rods are motor-operated remotely from the instrument panel. A selsyn system is used to operate an indicator located on the panel which shows the position of the rods at all times with reference to the center of the core.

INSTRUMENTATION

The instrument panel, which is illustrated in the Remley paper, Fig. 4, p. 23, was designed to provide the necessary instrumentation of the sensing devices and control and safety rods required by the specifications set up by the nuclear designers. The block diagram for these arrangements in shown in Fig. 12.

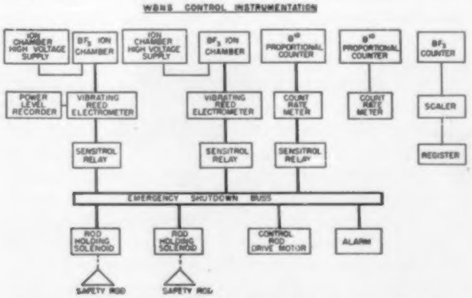

FIG. 12. Block diagram showing neutron detection instruments used, auxiliary instrumentation and the emergency shutdown actuators.

Three separate sensing systems operate to shut down the reactor and sound the alarm in the case of a reactor overload.

SHIELD

Figure 13 shows the biological shield which was designed to be adequate for the radiation field present, yet demountable in case varying experimental ar-

FIG. 13. Concrete shield blocks stacked to provide a biological shield to protect operators from radioactivity during reactor operation.

rangements of shield should be required or in case of a complete change of site for the reactor. Concrete blocks 2 feet square by 1 foot 10 inches high were selected. Vertical joints were staggered at assembly and the corner blocks were interlocked. Some of the

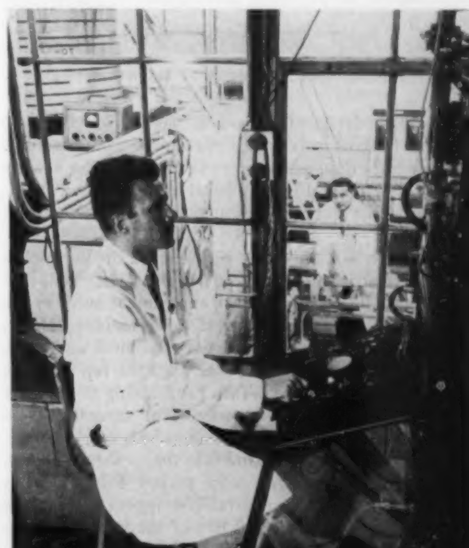

FIG. 14. Engineers check the operation of the control rods and instrument panel for the North American Aviation water boiler type atomic energy reactor prior to starting.

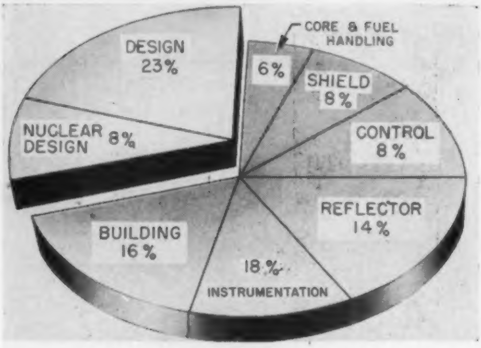

FIG. 15. NAA WBNS cost breakdown.

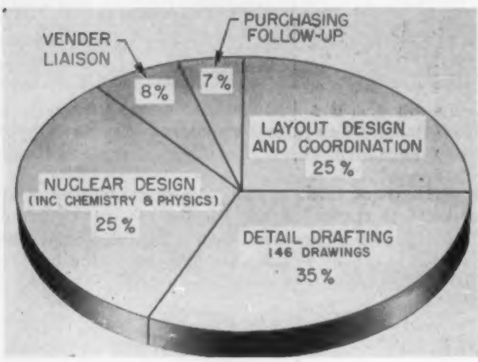

FIG. 16. Cost breakdown of engineering.

blocks were designed in special shapes to give passage for control rods or the movable graphite stringers. Accurate dimensions were essential to the success of such a shield and an appraisal of fabrication facilities was undertaken by visiting many concrete product plants.

When final assembly time was reached the key blocks which were adjacent to the control and safety rods and the special blocks opposite the experiment holes in the reflector were first located and the remaining blocks filled in to suit. It was necessary to level and shim all the blocks of the lowest layer until the top surfaces of all were in one plane before progressing to the next layers. By doing this a successful assembly was achieved and a source rod could then be passed through shield block and reflector and into the exposure hole in the sphere; the control rods passed freely within graphite walls and the removable stringers of graphite could be transferred in and out of the reflector without difficulty from outside the shield.

Building

A roof and housing of corrugated steel lined with insulation, covering a floor area 20 by 40 feet in size was provided adjacent to existing laboratory buildings in the North American Aviation plant in the city of Downey, California. A one-ton bridge crane was provided to serve the entire building. The elevation of the hook at the maximum height position was 20 feet. This height was required to withdraw lattice members about 6 feet long from a 6-foot experiment tank set on top of the graphite. Figure 14 shows the control console placed in an adjacent room whose floor level was very convenient as the operator seated at the console could see through a window all over the reactor room and check control rod responses to adjustments made at the console.

A cost breakdown of the North American Aviation WBNS is shown in Fig. 15. These percentages are given to indicate the relative costs of the various components of the one-watt power reactor previously described and include the total cost of manufacture, installation, and testing of the respective components. The cost of the fuel is not included. For a higher-powered reactor, the cost of a cooling system, additional cost of a more complete gas handling system and a more adequate shield would change the figures materially. The largest single cost is for engineering and design (31 percent) and is representative only for the first unit. A further breakdown of the design costs is shown in Fig. 16. Although the engineering design costs appear to be high, it must be remembered that this was the first reactor designed to be operated as a part of an established industrial plant located in a heavily populated district. Thus every possibility was thoroughly explored in order that those responsible could be certain of the complete safety to the populace around the project. Careful exploration therefore involved study and consideration of many design layouts that were eventually discarded.

Fig. 17. Installation on the WBNS of an automatic control system designed for operating a 2000-watt reactor.

Since being placed into operation, this small research reactor has been useful in experimentation other than that originally contemplated. Figure 17 shows the testing of an automatic servo system designed for operating a 2000-watt reactor.

This small reactor is well within the economic limits customarily spent for conventional equipment. Depending on the nature of experimental facilities, shielding, and building required, such a unit may cost from $75,000 to $100,000. Located as it is within an existing manufacturing plant it has proved beneficial not only in the experimental program for which it was designed but also as a practical tool for testing and developing new reactor components and may therefore, contribute to a wider use of nuclear reactors both by industry and educational institutions.

The Engineering Design of the North American Aviation Homogeneous Graphite Research Reactor

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THE BASES for the North American homogeneous graphite reactor design are: it may be operated in a highly populated area, such as a university campus; it is safe for unskilled personnel to perform experiments in and around the machine; and there are no hazardous effluents. In addition to being a general research tool, the reactor includes facilities for simultaneous service irradiations to produce isotopes that might provide a source of income for the operating institution. It is to operate at a power of 135 kw with 1×10^{12} neutrons/cm^2/sec available in the experimental facilities. Low construction cost consistent with the above requirements is of prime importance. This is kept to a minimum by using commercially available parts, equipment, and materials, wherever possible.

The basic design for the homogeneous graphite reactor was chosen from a study of six different configurations of both liquid and solid moderator designs. The homogeneous graphite configuration presented the most economical and practical solution for the design of an extremely safe reactor which has no radioactive effluents. The core is a homogeneous mixture of graphite and uranium contained in a sealed core tank. It is homogeneous only in the nuclear sense; that is, in the intimate association of the moderator and fuel, so that at all times they will have the same temperature. Since the moderator temperature determines the minimum velocity of the neutrons and the probability of fission is sharply dependent on neutron velocity, an increase in moderator temperature will decrease the reactivity of the reactor. This phenomenon is represented by a negative coefficient of reactivity. It gives the reactor inherent safety and stabilization. Thus, an accidental increase in reactivity, which always causes a rise in moderator temperature, will be arrested before damage can occur. As a precaution against an accidental increase of reactivity, no access is provided to the interior of the core tank except after first removing the core assembly from the reactor. It should only be necessary to remove the core for refueling, and the design provides sufficient fuel to operate the reactor for 3.5×10^6 kw hr. Operating at full power on an 8-hr day, refueling would be required about every 10 years. Another important feature of this configuration is the large quantity of neutrons available for experimental use. Many irradiations may be conducted simultaneously without materially reducing the number of available neutrons. Thus, certain long-time high absorption experiments may be conducted without interfering with other short-time experiments.

The design lends itself to simple components. Because of the large amount of room in and around the core, the control mechanism is simple and rugged commercial parts are used throughout. The shield, too, is a convenient size for the location of many experimental facilities that will not interfere with one another. The coolant system is conveniently located in a room below the reactor so that radiation from the coolant is not a problem.

The homogeneous reactor as proposed is an octagon, with outside dimensions of 20.5 ft across the flats by 13.5 ft high. The experimental facilities that pierce the shield are arranged on each of the eight faces and on the top. Also on the top are the control rod mechanisms which move the six rods extending vertically into the core. These mechanisms extend 10 ft above the reactor. Beneath the reactor, in a special room, is the cooling system equipment. The coolant, D_2O, is circulated in a closed system through the reactor and a heat exchanger. The core is in the center of the shield and is surrounded by a 2-ft thick graphite reflector. A control console may be located anywhere near the reactor.

The shield is 13.5 ft high and only 6 ft thick. These dimensions are achieved by using an iron ore-coleman-

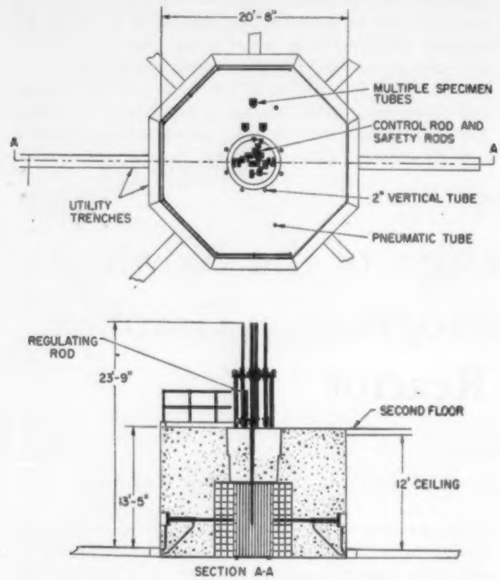

FIG. 1. General installation layout.

ite concrete for the shield. It has a specific gravity of 3.6 to 3.8, as compared to 2.3 for ordinary concrete. Thus, a substantial saving in the bulk of the shielding

FIG. 2. Core assembly.

is realized. The small size of the shielding makes it possible to construct the forms as concentric, ½-in. thick steel tanks with the experimental tubes and reinforcing steel welded in place. Perhaps this can be done at the fabricator's shop. The annular space is filled with the dense concrete at the construction site. The steel outside face is convenient for attaching special equipment or brackets to the reactor face, while the inner steel form provides a permanent vapor-tight envelope for the reflector graphite.

Experimental Facilities

Each of the eight faces of the reactor is 8.5 ft wide. This provides ample flat surface around a hole for assembling experimental apparatus and for providing a minimum of interference with the experiments that are being conducted in the adjacent faces. Each face has a radial utility trench that contains outlets for the electricity, water, and air below floor level. The trench connects with each experimental hole, so instrument lines may also run below the floor, thus preventing accidental damage to them by laboratory

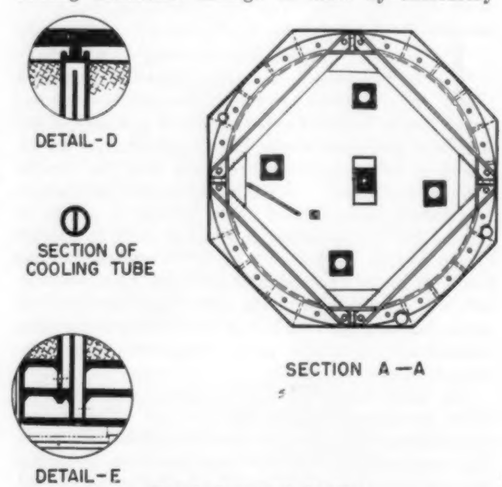

FIG. 3. Core tank details.

traffic. Four types of holes pierce the shield and reflector for inserting samples or equipment into the neutron flux: (1) the universal experimental hole, (2) the pneumatic tube, (3) the multiple specimen tube, and (4) the thermal column. These experimental holes are sealed from the atmosphere inside the reactor, thereby preventing radioactive air from emerging from the large void spaces in the reflector volume or the accidental drawing in or spilling of contaminants into the voids in the graphite reflector. There are 17 universal experimental holes, including four 3-in. diameter tangential holes, six 3.5-in. diameter radial holes, six 2-in. diameter vertical holes, and one 6-in. diameter radial hole.

In general, larger holes are preferred, but restrictions are placed on their size for: (a) convenience in

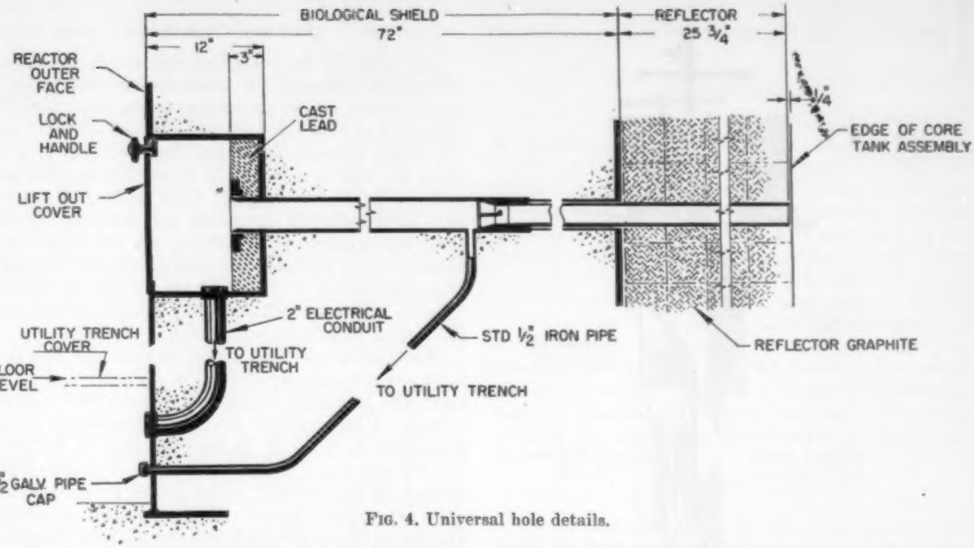

FIG. 4. Universal hole details.

handling and removing the shied plugs; (b) limiting the volume of high neutron absorbent material that may be placed into the hole because, if suddenly withdrawn, too large a volume would cause a runaway; and (c) limiting the amount of air in the tubes which may become radioactive and be displaced into the reactor room when the hole plugs are inserted. These three limitations indicate that, for this particular reactor configuration, hole of diameter 6 in. is the largest recommended.

Standard steel pipe is used for construction of the experimental holes in the shield. A thin removable aluminum thimble or tube is inserted through the reflector portion of the hole. It is sealed to the steel pipe by a gasket and nut. Aluminum is used to minimize the amount of neutron shadowing of the experiment placed inside the hole. The outer open ends of the holes terminate in a box or recess 16 in. square and 9 in. deep. Instrument leads or additional shielding may be installed in this recess. The holes may be sealed by placing a face plate over the open end, inside the recess. The hole may then be evacuated or purged through the ½-in. diameter drain and purge line. In addition, a 2-in. electrical conduit provides communication between the recess and the utility trench for instrument and power leads.

When a hole is not in use, it is plugged with a set of graphite plugs in the reflector section and steel plugs in the shield section to reduce the emitted radiation to below tolerance levels. Each plug weighs less than 30 lb for easy handling. The plugs may be easily withdrawn with a special tool which is positively engaged on contact.

Universal holes are useful for irradiating samples either in static or dynamic systems. Items such as the piston rings or wearing parts on machinery may be irradiated for subsequent wear testing. Also, beam experiments, such as determining the time of flight of neutrons or testing shielding materials, may be performed.

The pneumatic tube that has access at the top of the reactor is a specialized form of a universal hole. The main feature is the reduced shielding required to introduce and remove samples while the reactor is in operation. This tube is constructed of aluminum and is a commercial pneumatic system size. Thus, all the equipment and technics used in commercial installations may be used without change. A 2-in. diameter tube is shown, but a wide variety of sizes and shapes are available. This equipment is especially useful for the determination of the half-life of extremely short-life isotopes and for other controlled exposure experiments.

The thermal column, as shown, occupies one entire face of the reactor. Depending on the requirements of the research program, a thermal column initially may be made to cover more than one face, may be made smaller, or may be omitted. The size shown is 40 ft^2. The lead barrier between the reflector and the thermal column graphite shields the gamma rays produced in the core and allows only the neutrons to enter. Thus the emerging beam is composed of neutrons and gamma rays produced in the thermal column by the capture of neutrons in the graphite. A lead and cadmium door of 9-in. thickness is provided for shielding when the thermal columns is not in use. This door weighs 23,000lb. It is horizontally divided in the center and counterbalanced to move apart vertically. It is actuated by a pneumatic cylinder.

Some longitudinal bars placed in the graphite stack may be removed to make a very high-intensity short-range beam through one of the smaller doors in the large counterbalanced door. This beam would be useful for medical therapeutic work.

The general arrangement of the thermal column

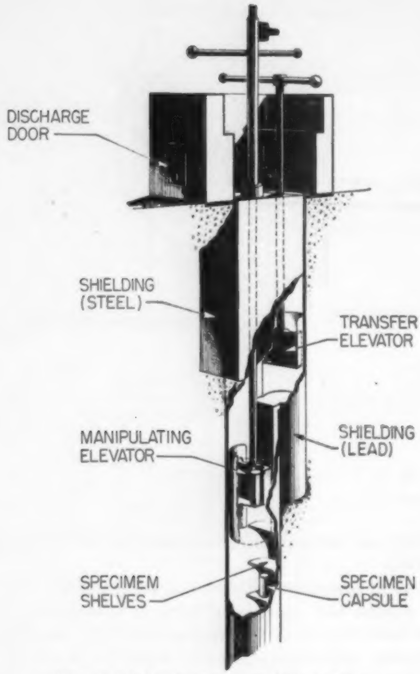

FIG. 5. Multiple specimen hole details.

makes it useful for exposing either a large number of test animals together or large areas of a material.

On the top face of the reactor are three multiple specimen tubes. Each consists of a vertical 5-in. diameter tube with small shelves placed at 3-in. intervals, and each terminates in a shielded transfer box. The transfer box eliminates the use of shield plugs and makes easier the transfer of the samples into a shielded casket. Standard 2¼-in. diameter by 2½-in. high, 25-cc sample capsules are provided which may be placed in the reactor and removed without disturbing any other capsule. A capsule is introduced in two steps. First, it is lowered to the offset in the transfer box; then, by rotating the paddles on each of the elevators in turn, it is transferred to the main elevator. The elevator is lowered to the selected shelf and again, by rotating the paddle, the capsule is transferred to the shelf. To remove a capsule, the procedure is reversed, and the capsule is finally discharged into a shielded casket.

The multiple specimen tube is a single-use device designed for the production of commercially usable radio isotopes or for long-time experimental exposures.

The experimental facilities were selected to give access to a variety of simultaneous experiments. The arrangement was chosen to provide the greatest amount of general purpose use. Other arrangements may be selected according to the needs of the operating organization.

Cope and Core Tank

The safety of the reactor is inherent in the design of the core assembly. The homogeneous core, which is homogeneous only in the nuclear sense, has a negative coefficient of reactivity of the order of -3×10^{-4} per °C. Under runaway conditions the coefficient is a bit lower but still is sufficient to arrest the reaction and to keep the aluminum parts from melting. By using only solid materials (graphite and uranium) in the core, the problem of containing all the fission and decomposition products was resolved simply by evacuating and sealing the core tank for the life of the core. Thus no radioactive effluents may escape and the need for a stack or hold-up equipment is eliminated.

That part of the core which contains the fuel is a right circular cylinder 45.5 in. in diameter and 42 in. high. The core tank, which contains the core and the portion of the reflector graphite immediately above and below it, is 46 in. in diameter and 93 in. high. The reflector was included inside the core tank to make removal of the assembly easier and to provide expansion space for the fission and decomposition products. The design of the core tank was complicated somewhat by including the reflector, but the simplification in gas handling and in the installation and removal procedure made it worth while.

The core tank design was interesting in that the tank, 46 in. in diameter and 93 in. high, was to be made of aluminum, evacuated to 2 cm of Hg with a helium atmosphere, made with as little metal in it as possible, and to have 70 re-entrant cooling tubes 1¼ in. in diameter passing, in an 8-in. rectangular lattice pattern, from the bottom through the core. The estimated temperature of the tank wall was 400° F.

The external pressure gave us the most concern. It was necessary to prevent a positive pressure from developing in the tank during its lifetime. This was specified so that, if a leak occurred, gas would leak in and trip a pressure monitor; whereas, if the tank were pressurized, gas would leak out and contaminate the room.

To develop strength with low neutron cross section, 52-SO aluminum was chosen for all the structural members. The tank wall was stressed for 2000 psi at 400° F. For these conditions, the wall was made ¼ in. thick, with stiffeners having a moment of inertia of 0.3 in.[4] placed at 12-in. intervals. A long thin section, ⅛ by 3 in., was selected for the external ribs. They were prevented from buckling by filling the space between each rib with graphite bars, which also made the transition from the round core tank to the octagonal reflector stack. The bars are held to the tank by a perforated aluminum girdle.

The creep rate of 52-SO aluminum at 400° F and 2500 psi is about 5×10^{-7} in./in. hr. This is excessive. Therefore, cooling coils were placed around the tank walls to reduce the temperature to 200° F. At this temperature the creep rate is not significant below a stress of 12,000 psi. These cooling tubes are manifolded and fed separately from the main coolant flow. Thus, a failure in the tank wall coolant system would

not be cause for immediate shutdown of the reactor, as the system can be independently turned off and the tank is adequate except for creep at the higher temperature.

The main coolant flow is manifolded from two plenum chambers in the bottom of the core tank. The 70 coolant channels are divided longitudinally in the middle, and the coolant flows up one side and down the other. The corrosion allowances were based on the assumption that turbulent flow gave lower corrosion rates. Therefore, the tubes were figured for a Reynolds number of 6500 and were made 1/8 in. thick. The plenum chamber has a very low Reynolds number, and the walls are 3/8 in. thick. Erosion at these velocities has been neglected. The tubes extend to the top of the tank to support the atmospheric load.

Five thimbles run vertically through the tank to permit entry of the control and safety rods. The rods are placed inside the core to prevent their shadowing the experimental facilities, as they would if placed outside the core. Located in the center thimble is also a separate 4-in. square element. Normally this element is filled with graphite, but if it becomes desirable to increase the fuel loading in the core, this element may be replaced with a fuel loaded element which can be connected to the D_2O cooling system. One might think of this as a means of rejuvenating a partially depleted core.

Core Removal

The core assembly is removed from the reactor by the following procedure. The control-shim rods are dropped from their magnets into the core. All the control and safety rod machinery is removed, and the top concrete shield plug is removed. The reflector graphite provides enough shielding so that radiation is not extra hazardous during this operation. A lead casket is moved over the opening; and, after having first cut off the four coolant feed lines flush with the bottom of the core tank, the core is raised into the casket by its permanently attached lifting sling. The casket and core are lifted together onto the casket bottom, which is secured, and the assembly is ready for transportation to a disposal site. The new core may be installed without the casket. The core exchange should take about two weeks.

Cooling System

The cooling system is a two-fluid circuit connected by a single-pass, one-tube, hairpin heat exchanger. D_2O is in the primary or reactor side, and ordinary water is in the secondary or heat-dump side. The pri-

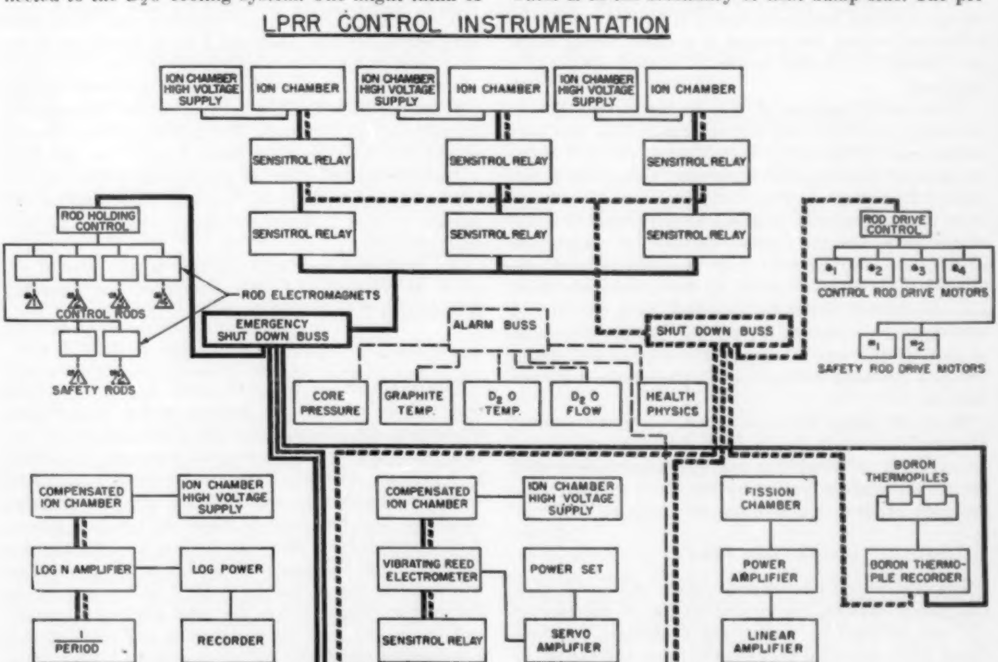

Fig. 6. Control circuit block diagram.

FLUX RANGES OF THE CONTROL INSTRUMENTS

Power Level	Thermal Flux at (Center of Reactor) $n/cm^2/sec$	Neutron Flux at Instruments $n/cm^2/sec$	LEVEL INDICATING INSTRUMENTS: Compensated Ion Chamber and Vibrating Reed Electrometer	LEVEL INDICATING INSTRUMENTS: Fission Chamber & Count Rate Meter	SAFETY INSTRUMENTS: Parallel Plate Ion Chambers Sensitrol Relays	SAFETY INSTRUMENTS: Boron Thermopile and Recorder
200 KW	10^{12}	10^{10}				
20 KW	10^{11}	10^{9}				
2 KW	10^{10}	10^{8}				
200 Watts	10^{9}	10^{7}		Withdrawn from Reactor		
20 Watts	10^{8}	10^{6}				
2 Watts	10^{7}	10^{5}				
0.2 Watts	10^{6}	10^{4}				
0.05 Watts	2.5×10^{5}	2.5×10^{3}				
0.02* Watts	10^{5}	10^{2} to 10^{3}				

* Lowest Power level with 1 gram Ra Be neutron source in reactor at initial start up.

FIG. 7. Range of control instruments.

mary circuit is 100 per cent 2S aluminum to minimize corrosion, and the secondary circuit is galvanized iron pipe. Most of the equipment in the cooling system, which consists of the D_2O pump and sump tank, exchange columns, heat exchangers, H_2O pump, and miscellaneous valves, are located in a small tunnel below the reactor. A cooling tower is located outside the building.

There are 65 gallons of D_2O in the system. This is circulated at 50 gal/min through the reactor and heat exchangers. To keep the D_2O at high purity for the purpose of reducing corrosion rate, 1 gal/min is bypassed through the resin exchange columns. The sump-type pump is totally enclosed in the sump to avoid rotary seals for the helium atmosphere maintained over the D_2O. All effort is made to prevent contamination of D_2O by H_2O which, if the atmosphere were not maintained, could be absorbed from the air. A blow-by valve connects the reactor to the sump tank so that, if the core overheats, the reactor will dump before a pressure buildup can damage coolant system or core.

The D_2O enters the core at 140° F and leaves at 158° F. The wetted area in each of the 70 tubes is 117 in.^{2}, or 8200 in.^{2} total. The heat exchange then is 9702 btu/ft^2 hr and is limited by the poor thermal conductivity of the graphite uranium mixture.

Control Rods

The control rod mechanisms, which are simple rack and pinion devices, are located on top of the reactor and are enclosed in vapor-tight containers to avoid direct communication between the room and the air in the reflector volume. The drive in all cases is a 1/20 hp, 3-phase, gear reduction motor. By selection of appropriate gears, the control rod speeds may be 4 to 75 in./min. A manually adjusted stop on the control rods limits the amount they may be withdrawn and serves as a shim adjustment; hence the name, control-shim rod. All the rods are held to the rack by electromagnets, which in case of emergency are de-energized and allow the rods to fall freely. They are arrested by an automotive type shock absorber.

The control-shim rods are stainless steel tubes filled with boron carbide. They are 2 in. in diameter, 42 in. long, and weigh approximately 40 lb each. Each rod controls 1.2 percent reactivity, or approximately 0.03 percent per inch. Cooling is by radiation to the cooled thimbles of the core tank. The safety rods are similar except that they are rectangular, 2 by 3.5 in., and have a graphite extension on the bottom which fills the hole when they are withdrawn. Each of these controls 5.0 percent of the reactivity, or approximately 0.12 percent per inch.

An automatic regulator rod may be provided if desired. It consists of counterbalanced rod assembly driven by a Brown Instrument 2-phase motor.

Instrumentation

The instrumentation for the control system has been designed to control the reactor under normal and emergency conditions. Since the total amount of excess reactivity for experimental purposes is limited to 2 percent, a simple instrument system is adequate. A fission chamber is used to bring the reactor from shutdown to a flux level of about 10^{-6} of full power. A compensated ion chamber is then used to monitor the level up to full power. In addition, a log amplifier will indicate the period from 10^{-10} full power up to full power. Simple relays are used wherever possible, and in the ion chamber instrument and relay circuit a response time of 300-millisec is expected. This speed is adequate, since a change in reactivity of 0.7 percent corresponds to a period of about 1 sec.

Three ion chambers, two compensated ion chambers, and one fission chamber comprise the sensing instruments for controlling the reactor. Two boron thermopiles act as an emergency alarm and shutdown device.

These are connected to form an emergency shutdown buss and a normal shutdown buss. A separate alarm buss monitors the core tank pressure, graphite temperature, D_2O temperatures, and D_2O flow. Erratic behavior of these will not shut down the reactor but will sound an alarm. Remote rod-position indicators, rod-holding magnet current, and various other minor instrumentation are not tied into any one of the three main buss systems.

Present Status

This reactor has been designed up to the point of making detail drawings of the various components. The technique of mixing graphite and uranium for the core has been worked out in full scale and was tested by a small scale experiment in another reactor. Other components are combinations of commercial parts in straightforward design. It is estimated that the cost of this reactor would be approximately $500,000, the exact amount depending on the extent of experimental facilities to be associated with it. The reactor described has the benefit of a very conservative design, and every effort has been made toward simplicity. It is a unit that will meet the requirements of safety while operated by unskilled personnel such as students in universities or technicians in a research institute.

Operation of the North American Aviation Water Boiler Neutron Source[1,2]

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A LOWPOWER HOMOGENEOUS REACTOR of the water-boiler type (*1*) has been in operation at the Atomic Energy Research Department of North American Aviation since April, 1952. This reactor, called the Water Boiler Neutron Source, or WBNS, was designed primarily as a source of neutrons for experimental purposes. The reactor is operated at power levels up to 1 watt, and at this level it supplies a maximum thermal flux of approximately 4×10^7 neutrons/cm² sec at the center of a test hole through the spherical core, along with somewhat lesser values of flux in exposure facilities in the graphite reflector.

The WBNS is well suited for neutron absorption cross-section measurements by the danger coefficient technique because of its low nuclear cross section which results in a high sensitivity. It is an economical type of reactor on which personnel training, instrument and material testing, along with other reactor engineering studies, can be conducted. It will furnish sufficient neutron flux for a great many types of neutron irradiations for studies in nuclear physics, radiochemistry, and biophysics. The water-boiler-type reactor also combines strong inherent safety features with the above characteristics. These result from the very large negative temperature coefficient and negative power coefficient of reactivity. These negative coefficients are sufficient to shut down the reactor in the event of accidental releases of large amounts of reactivity. This shut down will occur with a relatively small release of energy.

[1] Based on a paper presented at the 1953 Conference on Nuclear Engineering at the University of California, Berkeley, Sept. 9–11, 1953.

[2] Based upon studies conducted for the Atomic Energy Commission under Contract AT-11-1-GEN-8.

Description of the WBNS

The WBNS is a light-water moderated graphite reflected solution-type reactor. The core consists of a solution of highly enriched uranyl nitrate in a 1-ft diameter stainless steel sphere. The sphere has been constructed from two hemispherical spinnings of Type 347 stainless steel sheet, 1/16 in. thick, and has a volume of 14.38 liters. A central exposure facility in the core has been formed by inserting a tube, 1⅛ in. ID, through the sphere with its center line 3 in. below the horizontal diameter of the sphere. This sphere is encased in a cylinder of pile grade graphite, 5 ft in diameter by 6 ft high, which serves as a reflector and vertical thermal column. The entire cylinder is surrounded by a concrete block radiation shield 2 ft thick. A sectional assembly of the reactor is shown in Fig. 1. Figure 2 is a photograph of the installation with an experimental tank on top of the vertical thermal column.

The graphite reflector was formed by stacking graphite bars, $4\frac{1}{8} \times 4\frac{1}{8}$ in. in cross section, horizontally inside a steel tank with the bars in alternate layers placed orthogonal to each other. Eight of these graphite bars, or "stringers," near the sphere, as shown in Fig. 1, can be removed to form radiation exposure facilities. Parallel to the removable stringers is the central exposure facility which passes through the graphite and through the stainless steel sphere and permits access with small samples to the region of highest flux.

The reactivity control is maintained with two safety

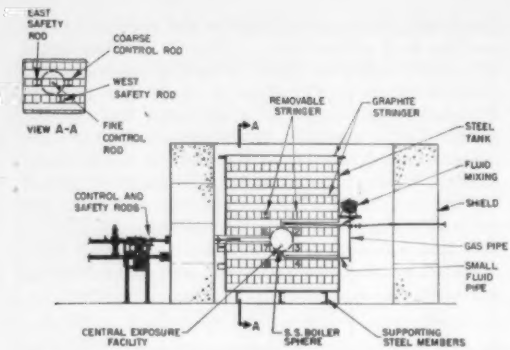

Fig. 1. Sectional view of WBNS showing locations of the stainless steel sphere forming the reactor core, the control and safety rods, the central exposure facility through the graphite reflector and through the sphere, and the removable graphite stringers which give additional neutron irradiation facilities.

rods, east safety and west safety, a coarse control rod and a fine control rod, located as shown in Fig. 1. These rods move horizontally through the concrete shield and into the graphite reflector adjacent to the stainless steel sphere. Each safety rod is constructed of two ¼-in. thick strips of Boral attached to aluminum channel beams. This forms an I-beam about 3 ft long and 4 in. high. The rods are removed from the graphite reflector manually and are held in the "out" position by magnetically actuated latches. If the holding magnets are de-energized, the safety rods are pulled into the reflector in approximately 0.5 second by weights suspended from cables placed over pulleys.

The coarse control rod is constructed similarly to the safety rods, but with cadmium sheet instead of Boral as the neutron absorber. The motion of this rod is obtained with a reversible electric motor drive system. The traverse of the rod is 80 cm, and approximately 155 seconds are required for the movement from the "in" position to the "out" position.

The fine control rod, which is used as an automatic power regulating rod, consists of a 1-in. diameter steel pipe with provision at the end for insertion of varying amounts of cadmium. At present, this rod controls approximately 0.1 percent in reactivity. The automatic control feature utilizes a Brown servo-amplifier whose input is the difference between the signal from one of the electrometers monitoring the neutron level of the reactor and a variable standard signal. The output of the amplifier drives a two-phase motor (a chart-drive motor from a Brown chart recorder), which in turn drives the fine control rod through a suitable gear train. Each of the control rods is provided with a selsyn remote indicator. The installed control and safety rod mechanisms are shown in Fig. 3.

Figure 4 shows a view of the instrument control panel which is located in a laboratory area immediately adjacent to the reactor. Four neutron flux measuring instruments placed at different positions around the graphite reflector are used for monitoring the power level of the reactor. Two of these are BF_3 ionization chambers connected to vibrating reed electrometers. The others are a boron-lined counter connected to a counting rate meter and a BF_3 proportional counter connected to a scale of 128 sealing unit. A Brown recorder located in the instrument panel continuously records the signal from one of the ionization chambers to provide a permanent record of the reactor power level. Sensitrol relays are connected to the output of each electrometer and to the counting rate meter. Operation of any one of these three relays will release the safety rod latches and shut down the reactor.

The gases that are evolved from the fission process and from the decomposition of the solution are collected in a gas accumulator tank of stainless steel of approximately 40 liters volume. The inside of this tank is divided by a Neoprene rubber bag, and the gas is collected between the outside of the bag and the inside of the tank. When necessary, the gas can be removed by transferring it from the accumulator to a storage vessel.

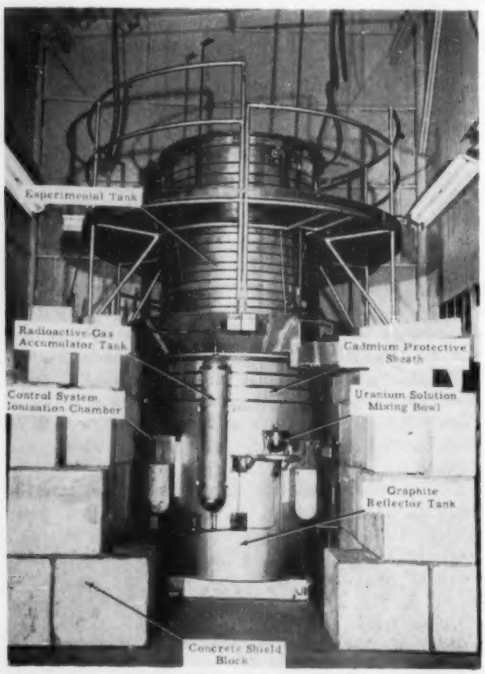

Fig. 2. Completed WBNS assembly with one shield wall removed. Lower tank contains graphite reflector and spherical core. Upper tank is experimental equipment.

Critical Assembly

The critical assembly was performed by making successive additions of highly concentrated uranyl nitrate solution to the reactor core. Prior to the addition of any fissionable material, 11,980 cm^3 of distilled

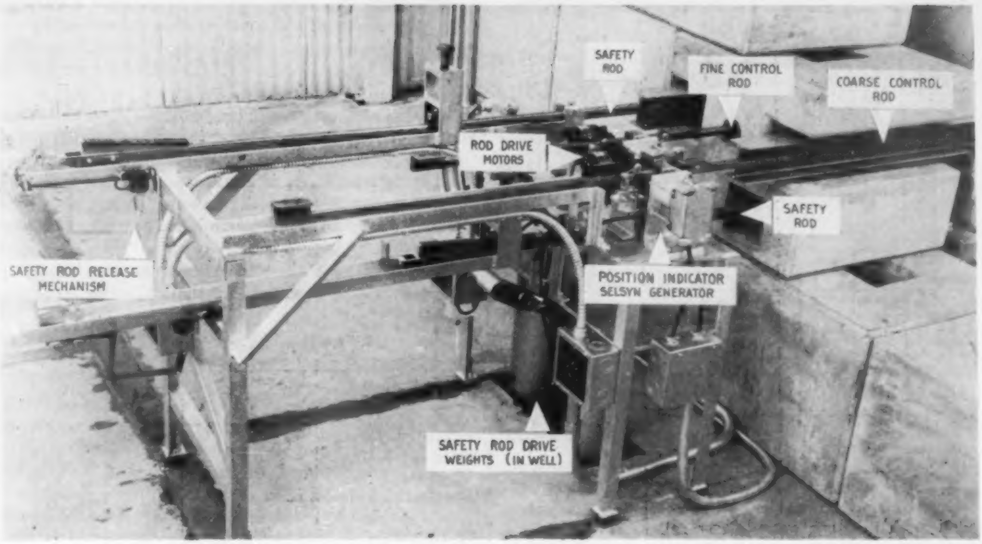

FIG. 3. Control and safety rod mechanism.

water was added to the stainless steel sphere, and the fuel system was flushed with helium. After each addition of fissionable material, measurements were made on the change in reactivity produced by the addition of the U^{235}. The changes in reactivity were observed by the multiplication of a 5.7-curie Po-Be neutron source inserted in the central exposure facility up to the center of the tube through the sphere. The measurements were made with suitably located BF_3 ionization chambers, boron-lined neutron counters, and with indium foils (approx. 90 mg/cm²) located in the graphite reflector, along a radial line from the edge of the sphere out to the edge of the graphite. Plots of the reciprocal counting rates as functions of the amount of fuel in the sphere permitted an extrapolation to the critical mass some time prior to the attainment of the critical state. Typical results are shown in Fig. 5, and from these the critical mass with all the control rods retracted is found to be 633.9 g of U^{235}.

A total of 638.2 g of U^{235} was added to the reactor core. This amount of fissionable material was sufficient to give a divergent chain reaction with a period of 26 sec, corresponding to an excess reactivity of 0.21 percent. A mass coefficient of reactivity for the WBNS was determined to be 0.050 percent per gram of U^{235}. The mass coefficient of reactivity for LOPO (*1*) was determined by means of a "boron bubble" experiment to be 0.0548 percent per gram of U^{235}. It is interesting to note here that these mass coefficients appear to be inversely proportional to the critical masses of the two reactors, that is,

$$(\Delta k/\Delta M)_{\text{WBNS}}(M_c)_{\text{WBNS}} = 0.050 \times 633.9 = 31.7,$$

$$(\Delta k/\Delta M)_{\text{LOPO}}(M_c)_{\text{LOPO}} = 0.0548 \times 565.5 = 31.0.$$

During the critical assembly, measurements of the multiplication of the neutron source were also made with the coarse control rod completely inside the reflector. Extrapolation of the reciprocal counting rate versus amount of U^{235} for these data indicates the absorption of the coarse control rod to be equivalent to 21 g of U^{235}. Using the afore-determined mass co-

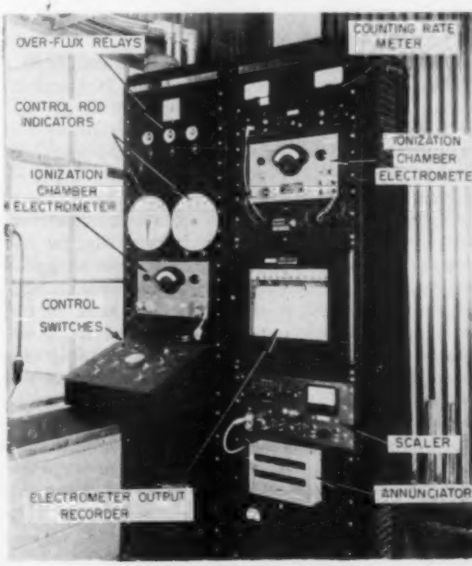

FIG. 4. Control console for WBNS located immediately adjacent to the reactor room.

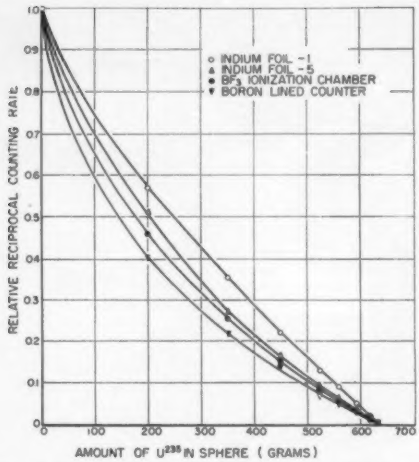

FIG. 5. Data obtained with three types of neutron detectors during the critical assembly of the WBNS. The reciprocal counting rates have all been normalized to unity with the sphere essentially full of water, with no fissionable material present. The extrapolated critical mass from these curves is 635.7 g of U^{235}. This amount, less the 1.8 g equivalent absorption of the Po-Be source, gives a critical mass of 633.9 g of U^{235}.

efficient of reactivity, one finds that the coarse rod controls 1.05 per cent in reactivity.

Operational Characteristics

The WBNS is started into operation with a 250-millicurie Ra-Be neutron source inserted in the center of graphite stringer No. 4 (see Fig. 1). This source emits about 3×10^6 neutrons/sec, which results in a "shut-down" power level of the reactor of about 0.5 milliwatt. A very large part of the operation is carried out with the source in place in the reflector. This results in quite a stabilizing influence on the operation, particularly at the low-power levels at which the reactor is operated.

Control and Safety Rod Effectiveness. The reactivity control of the safety rods individually, the two rods together, and the safety rods plus the coarse control rod has been determined. Since the reactor loading and the amount of control by the coarse control are known, k_{eff}, the reproduction factor for the reactor, is known for the subcritical state produced with the safety rods withdrawn and the coarse control rod completely in the reactor. The relative multiplications of a Po-Be neutron source inserted into the sphere of the reactor were determined with this configuration of control and safety rods and with other appropriate subcritical configurations necessary to determine the amounts of control desired. The multiplication M in these subcritical states will be given by

$$M = \left(\frac{1}{1 - k_{eff}}\right). \tag{1}$$

Then, from two measurements of relative multiplications for different rod configurations, one obtains

$$(k_{eff})_1 = 1 - \frac{M_0}{M_1}\left[1 - (k_{eff})_0\right], \tag{2}$$

where M_0 and $(k_{eff})_0$ are the multiplication and reproduction factor for the known subcritical configuration, and M_1 is the measured multiplication for a configuration in which $(k_{eff})_1$ is unknown. After values of k_{eff} for these unknown configurations have been determined, the amount of control in the rods is readily obtainable.

The results of these measurements are shown in Table 1. It is to be noted that there is some shadowing

TABLE 1. Reactivity control of control and safety rods in WBNS.

Rods	Reactivity Control (%)
Coarse control rod	1.05
East safety rod	1.45
West safety rod	1.17
Coarse rod and east safety	2.44
Coarse rod and west safety	1.93
East safety and west safety	2.44
Coarse rod and both safety rods	3.27

between the rods, since in none of the cases is the amount of control by the two rods together equal to the sum of the amount of control by each rod separately. The two safety rods are identical in construction, but are located in different regions of the reflector (see Fig. 1), so the difference in reactivity control by these rods should be expected.

Power Calibration. The power level of the water boiler has been determined by measuring the thermal neutron flux in the central exposure facility. The power P of the reactor is given by

$$P = \frac{N_{25}\sigma_{25}\overline{nv}}{3 \times 10^{10}} \text{ watts},$$

where N_{25} is the number of atoms of U^{235} in the sphere, σ_{25} is the fission cross section of U^{235}, and $\overline{nv}$ is the average flux in the reactor core. From flux measurements in the Los Alamos water boiler (*2*), the average flux, $\overline{nv}$, is determined to be 0.74 of the flux at the center of the spherical core. Since the WBNS is very similar to the Los Alamos reactor, the flux distribution and ratio of $\overline{nv}/(nv)_{max}$ should be comparable. Hence, this value has been used for our determination. The neutron flux was measured with standardized indium foils that had been exposed to a known thermal flux. These measurements were then used to calibrate one of the BF_3 ionization chambers and the Brown recorder was used to monitor the power level of the WBNS. This absolute calibration is accurate to only about ± 30 percent because of a lack of accuracy in the standardization of the indium foils.

Gas Evolution. Gas evolution resulting from the dissociation of water on the absorption of fission product energy in the solution has been observed at

operating levels as low as 0.1 watt. The rate of gas evolution has been determined by the following procedures. After a period of operation in which the total fission energy release is determined from integration of the recorded power level, the gas in the accumulator system is removed into a known volume in which the pressure and temperature are measured. Samples of the gas are then analyzed for hydrogen content by mass spectrographic means. The rate of hydrogen evolution is then determined from the amount of hydrogen in the accumulator and the total operation for the period.

Several measurements of this rate have been made after periods of operation totaling 30–50 watt hr. Data from operation of the Los Alamos HYPO version of the water boiler (*1*) indicated that the rate of gas evolution would be about 7–8 cm^3 of hydrogen per watt hour of operation. Therefore, the afore-mentioned periods were chosen to prevent the possibility of formation of an explosive mixture of hydrogen and oxygen in the closed accumulator system. The measurements show the rate of hydrogen evolution to be approximately 10 cm^3/watt hr. The determinations are consistent, but this value for the rate of evolution is subject to the uncertainty in the power level calibration previously mentioned. However, the rate determined here is consistent with that obtained at Los Alamos. Further, there are indications that the rate is somewhat less (approx. 10–20%) at power levels of 0.1 watt as compared to operation at levels up to 1 watt.

Neutron Flux Distributions. Thermal neutron flux distributions in various available regions in the graphite reflector and in the central exposure facility have been measured by the activation of indium foils. Both

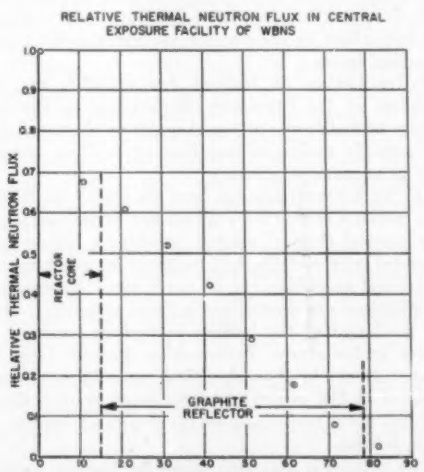

Fig. 6. Thermal neutron flux distribution in the central exposure facility of the WBNS. The flux has been normalized to unity at the center of this exposure facility, which is 3 in. below the geometric center of the sphere.

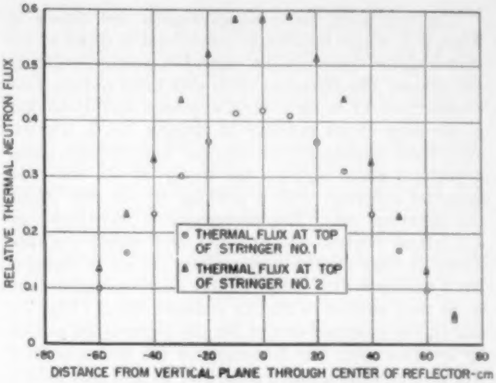

Fig. 7. Thermal neutron flux distributions at the top of two of the removable graphite stringers. The ordinate scale here is the same as that used in Fig. 3.

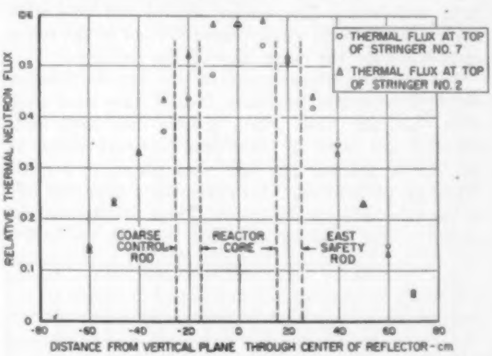

Fig. 8. Thermal neutron flux distribution in removable stringer No. 7. The distribution in stringer No. 2 has been plotted for comparison purposes. This latter distribution should be very similar to that in stringer No. 7 except for the effects of the control rod and east safety rod. The ordinate scale here is the same as that in Figs. 3 and 4.

bare and cadmium covered indium foils were used at each point to give the cadmium ratio (defined by the ratio of bare foil activity to cadmium covered foil activity) as well as the thermal neutron flux in each region. Most of the data were taken with indium foils 1 cm^2 in area and approximately 90 mg/cm^2 in thickness. The cadmium covers were small boxes made of 20 mil cadmium sheet. For the flux distributions in the reflector, the foils were placed in a milled slot in the top of one of the graphite bars. This slot was just large enough for the foils to fit easily into it. The flux distribution in the central exposure facility was determined with foils mounted on a 2-SO aluminum foil holder. This resulted in some "neutron streaming" along this hole through the reflector. During each exposure a monitor foil was placed in a standard geometry in the reflector. The activities of these monitor foils permitted a suitable normalization of the activities of all the different foils.

The results of these measurements are shown in Figs. 6–8, where the flux is normalized to unity at the center of the sphere in the central exposure facility in the sphere. The cadmium ratio with these indium foils varies from 3.7 in the central exposure facility to 36.0 at the edge of the reflector in stringer No. 1. The results show essentially symmetrical distributions about a vertical plane through the center of the core and graphite reflector, with a peaking of the flux inside the spherical core. The perturbations introduced by the coarse control rod and the east safety rod are shown in the flux distribuiton along the top of stringer No. 7 in Fig. 8. One should expect the distribution here to be very similar to that in stringer No. 2 (Fig. 7), and this is observed except for the depressions caused by the two rods. The flattening by the coarse control rod is somewhat greater than that by the east safety rod, since the safety rod was completely withdrawn from the reflector, and the contribution to the flux depression is that of the void from which the rod has been withdrawn. The coarse control rod was withdrawn about 35 cm which placed the end of the rod at approximately the outer edge of the stringer.

Independent measurements of the flux distribution through the central exposure facility have been made with "lindium" foils (75% indium and 25% lead) 0.2×1.0 cm and of thickness approximately 70 mg/cm^2 of indium. The foils were placed in a cylindrical graphite holder which essentially filled the void in the tube through the sphere. These results are presented in Fig. 9, along with data taken in the LOPO

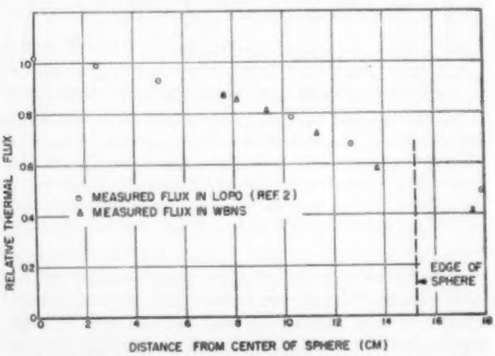

FIG. 9. Thermal neutron flux distribution in the central exposure facility of WBNS plotted as a function of the radius of the sphere along with similar data for LOPO at Los Alamos.

sphere (2) with a U^{235} ionization chamber. The two sets of data were normalized at the common point, 7.6 cm from the geometric centers of the spheres. This normalization is believed to be better than any other because of the difference in the reflectors of the two reactors, BeO for LOPO and graphite for the WBNS. The flux in the WBNS appears to fall below that in LOPO at the edge of the sphere. This is to be expected because of the greater production of thermal neutrons by the BeO reflector of LOPO compared to those produced in the graphite reflector of the WBNS.

Cadmium ratio measurements that have been made in the central exposure facility with foils of indium, gold, and manganese show that there is considerable fast neutron flux in the core of the WBNS. This property of a water boiler reactor could very possibly make it a useful source for the study of fast neutron radiation damage.

Experimental Uses

The WBNS has been found extremely useful as a neutron irradiation facility where a thermal flux of the order of 10^6 to 10^7 is required. Subjects for irradiation can be placed in the central exposure facility or in one of the removable graphite stringers. There is also a flux of about 10^6 neutrons/cm^2 sec per watt available at the top of the vertical thermal column. The calculated k_∞ for the reactor is 1.56, and hence the leakage probability is 0.360, so that a large leakage flux per unit power is available for experimental purposes.

The various experiments in which the WBNS has already proved to be a valuable tool include:

1. Testing and calibration of ionization chambers, boron trifluoride proportional counters, and boron lined counters for reactor instrumentation and neutron physics studies.
2. Irradiation of foils to be used in the development of absolute counting technics.
3. Irradiation of foils in the study of resonance absorption of neutrons in various elements.
4. Study of radiation effects in structure-sensitive materials.
5. Testing and calibration of health physics instruments.
6. Testing of various materials for neutron absorbing impurities by the danger coefficient method to be described below.
7. Irradiation of iridium for research by staff members of the Chemistry Department of the University of California at Los Angeles on electron-transfer isotopic exchange reactions of iridium complex ions in aqueous solutions.

Of great importance has been the use of the WBNS as a neutron source for exponential experiments (*3*). The vertical thermal column provides a rather large extended source of thermal neutrons on which various subcritical assemblies can be constructed. Neutron flux distributions are determined in these assemblies, which are mock-ups of the lattices in various types of reactors under study. Information derived from the measurements in the subcritical assemblies has contributed to the general knowledge of reactor theory and has aided materially in the design of specific reactor lattices.

The WBNS is also well suited for thermal neutron absorption cross-section measurements by the danger coefficient technic (*4*). This technic involves the insertion of a neutron absorber in a reactor which produces a change in the reactivity. By properly calibrating a reactor control rod with the insertion of known

amounts of neutron-absorbing material into the reactor core, the displacement of the control rod can be used as a precision measure of the absorption cross sections. Since the total neutron absorption cross section of the WBNS core is quite small (it has been calculated to be about 1440 cm^2), the WBNS is very sensitive to the effects of neutron absorbers inserted in the central exposure facility.

Apparatus for this type of measurement with the WBNS consists of a BF_3 ionization chamber located between the shield and the reflector. The signal from the ion chamber is fed to a sensitive galvanometer (10^{-10} amp/mm) which is used as a null device. The current from the ionization chamber is balanced by current from a standard source consisting of a potentiometer and a set of precision resistors. This is used to monitor the power level of the WBNS. Absorbing samples are placed in a specially fabricated graphite sample holder which is inserted in a reproducible geometry in the central exposure facility. The control rod position is indicated on a 36-in. steel scale which is mounted along side the channel in which the outer extremity of the control rod assembly moves external to the shield. A vernier fixed to this movable end of the control rod slides along the steel scale. This arrangement permits one to determine the position of the rod to ± 0.001 in.

The control rod has been calibrated with standard samples containing 3.72 mg of boron in the form of Bakelite impregnated with boric acid. As would be expected from the location and configuration of the control rod, the reactivity control is a nonlinear function of the control position. At a rod setting of approximately 26 cm (the control rod withdrawn 26 cm from the reflector), the reactivity control has been determined to be equivalent to 5.91×10^{-4} cm^2 of absorption cross section per mil of control rod. This is based on a neutron absorption cross section for boron of 750 barns (*5*). In this region it is found that the critical position of the control rod can be determined to within ± 0.002 in., so that the uncertainty in cross section for a given critical determination is $\pm 1.2 \times 10^{-3}$ cm^2. Since two determinations of the critical position are required for a cross-section measurement, the uncertainty resulting from the control rod settings alone is then only $\pm 1.7 \times 10^{-3}$ cm^2.

From period measurements, the reactivity control of the rod in the aforementioned region is determined to be 0.0141 inh/mil of rod. Using the inhour equation for a water-boiler-type reactor (*1*), this is found to correspond to 4.33×10^{-5} percent relativity per mil of rod.

At a control rod setting of about 60 cm, the effect of the control rod is equivalent to 8.3×10^{-5} cm^2 of absorption per mil of rod. In this region the critical position of the rod can be determined to within ± 0.008 in., so that the uncertainty in a cross-section measurement resulting from the control rod settings is $\pm 10^{-3}$ cm^2.

The great advantage in sensitivity of the WBNS for measurements using this technic is shown when one determines the effect on reactivity for a given cross section from the above data. This constant for samples placed in the central exposure facility of the WBNS is found to be 4.19×10^{-2} cm^2/inh. This can be compared to the constant obtained for the Argonne graphite reactor (*4*) of 2.05 cm^2/inh.

One of the problems associated with the danger coefficient technic is that of maintaining minimum extraneous reactivity changes in the reactor during the period required for the measurements. A method of surmounting this difficulty is to operate the WBNS at a very low power level, approximately 0.2 watt, so that changes resulting from temperature effects, power coefficients, and other variations in reactivity associated with high-power operation are minimized. The effects of any reactivity drifts are also greatly decreased by performing the measurements in a cyclic time sequence, that is, the critical position of the control rod is obtained for sample A, for sample B, and then for sample A again. The slow variation in reactivity is then averaged out.

To check the effects of possible variations in reactivity, a series of critical position determinations has been made at a power level of 0.2 watt during which nothing was changed in the WBNS except the small changes in the control rod required to determine the exact critical position. During the period required for the data taking, the reactor reactivity was observed to decrease, that is, the control rod had to be withdrawn slightly to keep the reactor critical. Plotting the critical position as a function of time during the experimental run, it was determined that the reactivity changed at an approximate rate of 1.05×10^{-2} inh/min. It should be noted that this rate of change of the activity varies from time to time and is not always negative. The value given here appears to be typical. A similar set of data was then taken at an operating power level about three times greater than the one used above. Again the reactivity was observed to decrease, but at a rate of only 1.77×10^{-3} inh/min. Phenomena that are strongly suspected of contributing to this slow variation of reactivity with time include the slight heating of the solution by the absorption of the fission energy, the possible build-up of the gases of dissociation in the solution, or a combination of these along with others.

In connection with the above problem, it is of interest to examine the uncertainty that a drift in reactivity of the magnitude observed would introduce in a cross-section measurement. The time difference between the two critical position determinations necessary for a cross-section measurement is about 1 hr. During this time a reactivity drift of approximately 6.3×10^{-2} inh might be expected on the basis of the above data. Thus, if no correction for the drift is made, an uncertainty in the cross-section determination of only about 2.6×10^{-3} cm^2 might be introduced. However, this uncertainty can be reduced considerably by making the cyclic measurements mentioned above.

It may be stated that the WBNS has proved to be an extremely versatile and useful tool for a great many

varied research programs. This type of reactor gives a very high neutron flux per unit power over a small region. The use of this particular design of a water-boiler-type reactor is somewhat limited because of its low power rating. However, with suitable design changes, the power rating can be increased many-fold so that a neutron flux of 10^{12} neutrons/cm² sec is easily obtainable.

References

1. Los Alamos Scientific Laboratory, "An Enriched Homogeneous Nuclear Reactor," *Rev. Sci. Instr.* **22**, 489 (1951).
2. KING, L. D. P., and SCHREIBER, R. E. "Distribution and Power Measurements in the Water Boiler," AECD-3054, October 19, 1944.
3. GLASSTONE, S., and EDLUND, M. C. *The Elements of Nuclear Reactor Theory*. New York: Van Nostrand, 1952.
4. ANDERSON, H. L., *et al. Phys. Rev.* **72**, 16 (1947).
5. "Neutron Cross Sections," AECU-2040, May 15, 1952.

News and Notes

Heavy-Water Reactor Conference in Oslo, Norway

AN international Conference on Heavy Water Moderated Nuclear Reactors was held in Oslo and at Kjeller, Norway, Aug. 11–13. The Conference was sponsored by the Dutch-Norwegian Joint Establishment for Nuclear Energy Research (JENER). There were about 100 participants, with representatives from most countries in the Western World. The program consisted of papers on reactor design and construction, kinetics and control, and neutron physics. Ample time was provided for discussions.

In his opening address G. Randers (JENER) discussed the possible use of heavy-water reactors in industry. Since most European countries are unable to procure enriched fuels at the moment and since even natural uranium is scarce and relatively expensive, a good moderator becomes essential. Furthermore, the geometry of the reactor must allow an initial reproduction factor which is adequate for a 1% burn-up of the fuel. Thus the call for a heterogeneous heavy-water moderated natural-uranium reactor. Design studies for such a reactor to produce 5000 kw of electricity are being made at Kjeller.

J. V. Dunworth (A.E.R.E., Harwell, England) underlined the advantages of using heavy-water as moderator in general. He maintained, however, that with the present high price of heavy-water it is difficult to make an electricity-producing reactor-plant which competes favorably with conventional plants. Where there is a need for a small, compact system the situation is more favorable.

As a pleasant break in the discussions on future reactors, J. M. West (Argonne, U.S.A.) described the latest Argonne research reactor CP-5. This reactor is a result of the experiences gained at Argonne with their earlier heavy-water moderated research reactors CP-3 and CP-3′. The latter reactors were described in a later session by West from a paper prepared by S. McLain. CP-3, which operated from early 1944 to early 1950, contained natural uranium as fuel. CP-3′ and CP-5, on the other hand, contained enriched fuels. The maximum slow neutron fluxes were for CP-3 about 10^{12} cm^{-2} sec^{-1}, for CP-3′ at 275 kw $3{,}4 \times 10^{12}$ and for CP-5 a calculated average thermal flux at 1000 kw of 2×10^{13}. The reason for using enriched fuel in the latter reactors is to obtain a greater fission rate per unit mass of fissile material. Heavy-water is preferred to light-water as moderator due to the larger reactor core for experimentation and the longer lifetime of slow neutrons. This makes the problem of control easier.

In a paper on the past, present, and future of heavy-water reactors L. Kowarski (Saclay, France) stressed that a greater excess reproduction factor can be obtained with a heavy-water moderator than with a graphite moderator. As a result the reactor is easier to construct and to run. In a situation where the abundance of pure fissile materials is low, the natural-uranium heavy-water system offers the best solution as a power reactor. This situation may, according to the speaker, last for more than 20 years.

A. M. Weinberg (Oak Ridge, U.S.A.) presented a description of the A.E.C. materials testing reactor (MTR) from a paper written by S. McLain. This reactor was designed so as to maximize the fast neutron flux. In order to achieve this it is necessary to make the power per unit cross-section for scattering of fast neutrons as high as possible. The volume of the reactor core for a given power is therefore made as small as possible. Highly enriched uranium-235 is used in the core and beryllium is used as reflector. At 30,000 kw the flux of uncollided fission neutrons is of the order of 10^{14} and the average slow neutron flux is 2×10^{14}. Weinberg also described briefly the Swimming Pool Reactor and the Homogeneous Reactor Experiment at Oak Ridge. The strong coupling which exists between the temperature and power in the latter reactor was discussed.

Some of the reactor projects in Europe were also treated briefly. L. Kowarski described the Saclay reactor, which is a natural-uranium–heavy-water reactor which is cooled by blowing compressed nitrogen gas along the rods. J. Bernot gave an account of the cooling system. O. Dahl (Norway) and P. Scherrer and W. Zünti (Switzerland) presented the plans for heavy-water moderated and cooled natural-uranium reactors with a heat generation of the order of 10,000 kw. S. Eklund (Sweden) gave some details of the

nearly completed research reactor in Stockholm. Finally M. Bustraan (JENER) reported on some calculations on thermal breeding by M. Bogaardt and himself.

The session on reactor kinetics and control began with a paper by A. Lundby (JENER) on the time behavior of the Kjeller research reactor (JEEP). From experiments by the speaker and N. Holt on the response of the reactor to step function changes in reactivity the average lifetime of a neutron in the reactor was found to be about 2.10^{-3} sec. The effect of the delayed photoneutrons was dealt with.

V. O. Eriksen (JENER) described measurements and calculations by W. Hälg and himself on the Xe-135 poisoning in the reactor. After about 2 days operation at 250 kw the Xe-135 suppresses a reactivity of about 2.10^{-3}.

A theoretical paper by W. K. Ergen and A. M. Weinberg on some aspects of nonlinear reactor dynamics was presented by Weinberg. The high power densities and large excess reactivities in more recently constructed reactors lead to a strong coupling between temperature and reactivity. The power in such reactors may change so rapidly that the stability of the system must depend on this coupling rather than on relatively slow acting control rods. Under the assumption of a negative temperature coefficient of reactivity the response of a reactor was calculated for different ways of extracting the heat.

V. Raievski (Saclay, France) reported on reactivity measurements with a subcritical reactor and compared them with results obtained by measuring the stable period of a supercritical reactor. The session was closed by a description of the control system of JEEP by K. P. Lien (Norway).

The last day of the Conference was devoted to neutron physics. A great number of short papers were given. The main speakers were J. A. Goedkoop (JENER) who reviewed beam experiments with JEEP, B. B. Kinsey (Canada) who discussed some results of recent gamma-ray studies at Chalk River, and P. A. Egelstaff (England) who gave results of measurements of pile spectra and cold neutron scattering experiments besides describing the fast chopper in Harwell. G. Randers closed the Conference by proposing the foundation of an International Nuclear Energy Society. The participants of the Conference agreed to this and suggested the establishment of a preliminary committee to work out further organizational details. The aims of the Society would be to distribute information (possibly through a periodical) organize meetings and standardize the nomenclature and symbols used in the field.

ARNE LUNDBY

Dutch-Norwegian Joint Establishment for Nuclear Energy Research
Oslo, Norway

Science News

Two responses evoked by **President Eisenhower's atomic proposals** to the United Nations are as follows.

Watson Davis, Director of Science Service, indicated that the chief value of the speech was that it provided an initial step toward cooperation, that the prime facts revealed were psychologic and diplomatic for, if Russia adopted all the Eisenhower proposals tomorrow, it would not remove the danger of atomic war. Mr. Davis pointed out that the President mentioned specifically "fissionable materials," which would not include the tritium, deuterium, or ordinary hydrogen that presumably is used in superbombs.

The Federation of American Scientists issued a strong statement of endorsement saying that the proposal for an international agency to develop constructive possibilities of the atom "would evoke enthusiastic support and willing service from most scientists and engineers." But the statement warned that "the road to abundant, useful atomic power is yet long and hard," and said that both the United States and the Soviet Union could profit by cooperation.

A survey published in the Dec. 7 issue of *Chemical and Engineering News* shows **increasing nuclear energy** activities in the countries of the free world. Further, the enormous budgets of the major powers do not discourage smaller countries, according to Gunnar Randers, director general of the Norwegian-Dutch reactor at Kjeller, Norway. He believes most of the large expenditures have given results now sufficiently well known to save similar expenses for others. By concentrating on a project of particular interest, a small country can turn out specific results that compare favorably even with those of the United States.

The survey shows that nonmilitary nuclear energy projects are under way or well along in planning in Norway, the Netherlands, Belgium, France, India, and Switzerland. These newcomers to the field are emphasizing either electric power from nuclear energy or radioactive tracers for chemical and medical research. There are also plans for power plants in Australia and Brazil. Germany is anxious to get into the field, but is still restricted by an Allied ban. In addition, the European Nuclear Research Center to be located in Switzerland will pool the resources of Belgium, the Netherlands, France, Britain, West Germany, Greece, Italy, Sweden, Denmark, Norway, Yugoslavia, and Switzerland. Another international group may be formed soon, the International Nuclear Energy Society; it would include participants from 19 countries and would attempt to distribute information, organize meetings, and standardize atomic nomenclature and symbols.

The **Government of India** is making an effort to raise the country's standard of living substantially, by means of atomic energy. A project has been inaugurated to convert soil with a high monazite content, plentiful in South India, into nuclear fuel. In

monazite there is 9% of radioactive thorium, and through an atomic pile this can be converted into energy. The reaction must first be started by the use of uranium, of which India has an adequate supply.

The program was discussed by H. J. Bhabha, of the Tata Institute of Fundamental Research and chairman of the Indian Atomic Energy Commission, at an international conference on theoretical physics in Japan. Prof. Bhabha described the work being carried out by hundreds of scientists from India as well as by many brought from overseas.

A special research center has been set up in Bombay in what was formerly an army installation. Foreign observers who have seen the plans and the work already in progress are greatly impressed with the way the Indian atomic project is being conducted. They point out that the Indians have the advantage of concentrating all their fissionable resources on a program for industrial use, whereas other countries have stressed the destructive aspects in the production of atomic energy.

In December the **Atomic Energy Commission** renewed its invitation to private industry to submit proposals for the investment of risk capital in the recently announced project to build a full-scale nuclear reactor for generating electric power. The AEC is proceeding as rapidly as possible with necessary decisions on architect-engineering considerations, site selection, and operating specifications. Companies or organizations interested in participating should submit proposals, *prior to Feb. 15,* to AEC Reactor Development Division, Washington, D.C.

The Geological Survey now possesses a modern **"atomic clock"** for dating mineralogical, archaeological, and prehistoric plant and animal remains. This clock, based on measurements of the natural radioactivity of carbon 14, is the invention of W. H. Libby of the University of Chicago. Its use offers one of the most fascinating achievements of the atomic age, and for the Survey has opened an entirely new approach to the study of the earth's past, especially glacial and postglacial times.

Atomic clocking is based on the observation that radioactive carbon 14, being manufactured constantly from the nitrogen in the atmosphere through cosmic ray bombardment and assimilated as carbon dioxide by living things all during life, provides a known fraction of tagged atoms whose rate of decay can be checked to determine, within certain limits, how long ago a given plant or animal lived. As long as an organism is alive, a balance is maintained between radioactive carbon and the ordinary variety. New radiocarbon is added as fast as the old disappears. When life ends no more is added, and in death the carbon timeclock begins to run down. Thus each piece of wood, for example, provides evidence of its absolute age, in addition to the evidence yielded by the calendar of its annual rings, which is limited to the life span of the tree from which it came.

Dr. Libby's ingenious method involves the measurement of the very low radioactivity remaining in the carbon of, say, wood, bone, or seeds, when placed within a special arrangement of Geiger counters. The half life of carbon-14 is 5568 years. Age determinations up to 20,000 years are fairly commonplace today, but beyond this point accuracy falls off swiftly.

The Department of Interior's clock is a modification of the Libby method and was developed by Hans Suess, Geological Survey physical chemist. It further reduces the carbon to acetylene gas, which can be introduced into a Geiger counter without allowing contamination by air molecules.

The General Electric Company has developed a powerful mechanical arm, named **O-Man** (for overhead manipulator), for use in radioactive areas where men could not survive. The machine was designed for the G-E Aircraft Nuclear Propulsion Department which is constructing an atomic aircraft engine under the sponsorship of the Atomic Energy Commission and the Air Force. O-Man's operator will run the controls from behind special glass windows, aided by binoculars or a telescope. The machine's chief function will be to pick up heavy parts, position them, and fasten them into place. It can drill and tap holes, use power wrenches, hammers, or riveters, and if need be, can handle a sheet-metal saw.

The first hospital designed specifically for atomic-age treatment, the **Argonne Cancer Research Hospital** at the University of Chicago, is the subject of an article by Robert Goldstein in *Today's Health* (Nov., 1953). The Atomic Energy Commission provided $4,200,000 for construction and will continue to defray operating expenses of approximately $1,000,000 a year. The main function of the hospital is to learn how radiation can help control cancer. Only two of the building's eight floors are for patient care. Two floors are devoted solely to fundamental research. Leon O. Jacobson, professor of medicine at the university and director of the hospital, emphasizes that the entire program comes under the heading of research.

The hospital has unusual safety factors such as 8-in. concrete walls, plastic floors, and lead isotope containers that fit inside stainless steel tubes extending 8 ft below the basement floor. Investigators watch certain operations through 3-ft thick windows containing a solution of zinc bromide. Five of these windows cost $10,000. Further, a health physics section establishes safety methods and is responsible for checking patients, personnel, and laboratories for contamination.

The institution is being equipped with a wider range of high-energy radiation machines than any other in the world. Nearly 300 untried radioisotopes will be evaluated and tested. Many of them are radioactive for very short periods, but isotopes can be delivered quickly from nearby Argonne National Laboratory.

One of the new devices to be used is the cobalt 60

"bomb," which is 1800 times more powerful than 1 g of radium and is equivalent to a two-million-volt x-ray machine in producing energy. The "bomb," like several other instruments being tested, is equipped so that it can be rotated around the patient. Extensive research will also be conducted on radioactive tracer techniques. The hospital's facilities will be available to the Argonne National Laboratory and to 32 Midwest universities and other research institutions that are participating members of the laboratory.

An article in *The Merck Report* **62**, 7 (Oct., 1953) entitled **"Atomic Energy for Human Diseases,"** by John T. Godwin, Head of the Division of Pathology, Brookhaven National Laboratory, outlines the following research.

Investigation of possibilities of the use of short half-life isotopes and thermal neutrons in humans at the hospital of the Brookhaven National Laboratory has been carried out with the few radioactive isotopes found useful in human diseases. Radioactive phosphorus (P^{32}), produced through bombardment of stable P^{31} or S^{32} by neutrons, with a half life of 14.3 days, is considered the agent of choice in the treatment of polycythemia rubra vera. Administration may be orally or intravenously. Effects of a single dose are evident in approximately two months. Vascular complications such as hemorrhage and thrombosis are reduced.

Radioactive iodine (I^{131}), a by-product of uranium fission, has a half life of 8.14 days and decays to stable xenon 131. This isotope has been used extensively in both the diagnosis and treatment of certain thyroid diseases. It is selectively concentrated in the thyroid colloid. It has been found useful in reducing the thyroid in patients with cardiac disease, and diffuse hyperplasia (Graves' disease), nodular hyperplasia, and in certain types of metastatic thyroid carcinoma. In cases where surgery has failed, or is not indicated, radioactive iodine has been effective in the management of hyperthyroidism. An undesirable side effect is hypoplasia of the bone marrow. The potential carcinogenic effect of iodine 131 in patients treated for hyperthyroidism has not yet been elucidated.

The short half-life isotopes are at present under investigation. Radioactive chlorine (Cl^{38}), produced in the nuclear reactor by neutron bombardment of pure ammonium chloride, has a half life of 37.3 min. A small number of cases have been treated in an attempt to reduce pleural and peritoneal fluid accumulations in pleural metastases of breast carcinoma and in peritoneal implants of ovarian adenocarcinoma. Reduction of fluid has been obtained in some of these cases. There was evidence of radiation effects on the pleura and peritoneum, with damage to the tumor; in one case there was hypoplasia of the bone marrow. Radioactive gold (Au^{198}), produced by neutron bombardment of elemental gold, has a half life of 2.7 days and decays to stable mercury 199. It has been used in a colloidal state, intrapleurally or intraperitoneally for metastatic carcinoma, in an attempt to diminish the accumulation of fluid. Some success, although little actual tumor destruction, was observed.

The application of the capture of thermal neutrons by boron atoms of mass 10, with a very high thermal neutron-absorption cross section, has been investigated in 10 cases of glioblastoma multiforme, since it was found that boron initially concentrates in certain brain tumors to a significantly greater degree than in the surrounding brain. E.M.L.

Nuclear energy has provided new **research tools for dentistry** that point the way to increased knowledge of tooth structure and dental disease and treatment, according to five reports appearing in a recent issue of *The Journal of the American Dental Association*. Research projects in the field have been completed or are in process in 17 institutions, including dental schools, the National Institute of Dental Research, and institutions of the armed forces. Some 21 radioactive compounds have been used in investigations.

"The developments which have occurred since 1945, when radioactive compounds were released in large quantities from the uranium pile at Oak Ridge, have each year brought new developments in dentistry," the *Journal* said, "and it appears now that dental institutions will need to establish radioisotope laboratories where graduate students can be trained in the use of these new tools of dental science."

Scientists in the News

Daniel H. Basinski of The Child Research Center of Michigan, Detroit, has recently accepted a position as associate biochemist in the Department of Laboratories at Henry Ford Hospital.

Herman Blaschko of Oxford University joined the Department of Pharmacology of the Yale School of Medicine in September as visiting lecturer and research associate. His work on the amine oxidases and on various aspects of amine metabolism has been of great importance. At Yale, studies initiated at Oxford by Dr. Blaschko and Arnold D. Welch on the concentration of epinephrine within cytoplasmic particles of the adrenal medulla will be continued.

The Navy has presented its highest civilian award, the Distinguished Public Service Award, to three research scientists of the Hercules Powder Company, Wilmington, Del., for "exceptional contributions to the United States Navy" by developing new propellants for guided missiles. Recipients of the awards were: **Lyman G. Bonner,** technical director of the Rocket Development Department at Allegany; **Ralph F. Preckel,** a research group supervisor; and **Richard Winer,** chief of the Rocket Development Department.

D. M. Brown has been promoted to the position of head of the Department of Data Reduction and Computation, Willow Run Research Center, University of Michigan.

D. Eugene Copeland, for the last 3 years on leave

of absence from Brown University to the Office of the Surgeon General, USAF, has been appointed professional associate in the Division of Medical Sciences, National Research Council, to be associated with the Committee on Growth.

William B. Deichmann has resigned as professor of pharmacology at the Albany Medical College to accept an appointment as professor and director of the Department of Pharmacology at the University of Miami School of Medicine, effective Oct. 1.

C. M. Hebbert, who has retired from his position at the Bell Telephone Laboratories, has been appointed to a professorship at the Polytechnic Institute of Brooklyn.

The American Society of Anesthesiologists has elected **Dennis Jackson,** professor emeritus of pharmacology at the University of Cincinnati, to honorary membership in recognition of his service to the profession. In 1915 Dr. Jackson developed in experiments with animals the basic techniques now used for human anesthesia. The Society's distinguished service award this year went to **Charles F. McCuskey** of Los Angeles, past president of the American Board of Anesthesiology.

D. T. O'Connor, chief of the Radiology Section, U.S. Naval Ordnance Laboratory at White Oak, Md., was awarded the First Annual William D. Coolidge Award as the author of the outstanding paper of the year on x-rays. The award was made jointly by the Society for Non-Destructive Testing and the X-Ray Department, General Electric Company. Mr. O'Connor's paper, entitled "Industrial Fluoroscopy," was published in the journal of the Society, and was presented at last year's session as the Mehl Lecture by which the Society honors outstanding members.

Jean Redman Oliver, professor of pathology in the College of Medicine at New York City, State University of New York, has been named the first Distinguished Service Professor of the University. Dr. Oliver, who has the longest record of service of any full professor on the faculty, will retire next spring after an association of 24 years. He is well known for his work in renal pathology, and is at present on leave from the University to conduct research for the U.S. Army Epidemiological Board on the renal lesions caused by epidemic hemmorhagic fever, a disease that has assumed considerable importance in connection with the troops in Korea. Until he accepted this current assignment, which is being carried out in Overlook Hospital, Summit, N.J., Dr. Oliver had been chairman of the Department of Pathology since 1929.

Russell L. Perry, of the University of California Department of Agricultural Engineering at Davis, assumed new duties Sept. 1 on the university's Los Angeles campus. Dr. Perry, who has been on the Davis campus for 25 years, transferred to U.C.L.A. as a specialist in agricultural engineering but remains on the agricultural engineering faculty at Davis. He will be attached to the College of Engineering at Los Angeles.

Robert M. Salter has transferred, for reasons of health, from the position of chief of the Soil Conservation Service to a post in charge of Soil and Water Conservation Research in the Agricultural Research Service. **Donald A. Williams** has been appointed acting administrator of the Soil Conservation Service. Mr. Williams has been in charge of the Agricultural Conservation Program since February and before that was assistant chief of the Soil Conservation Service.

E. W. R. Steacie, president of the Canadian National Research Council, was Baker lecturer in chemistry at Cornell University from November 10 to December 15. Dr. Steacie lectured on "Photochemical and Free Radical Reactions."

H. W. Stunkard, of New York University, completed his second five-year term as Chairman of the Editorial Committee and Managing Editor of the *Journal of Parasitology,* at the end of 1953. He will be succeeded by **George R. LaRue,** Bureau of Animal Industry, U.S. Department of Agriculture, Beltsville, Md. All manuscripts submitted to the *Journal* after Jan. 1 should be addressed to Dr. LaRue.

Education

Cornell University hopes to have its new high-voltage laboratory, replacing one destroyed by fire in 1948, in full operation within approximately a year. The massive windowless building of more than a half-million cubic feet will have a testing bay that occupies most of its space. Railroad cars will run onto the testing floor to unload transformers, insulators, and other heavy equipment.

The center, which will be directed by Stanley W. Zimmerman, will be capable of testing to destruction almost any electrical insulator. Fifteen-ton transformers will be able to produce 1,000,000 v, single phase, or 600,000 v, three phase. Capacitor networks will permit electrical surges as high as 3,000,000 v, with currents exceeding 25,000 amp. Engineers will be able to simulate a wide variety of conditions and to produce "standard" lightning strokes. Both man-made and natural lightning will be subjected to measurement. The laboratory will also be used for the investigation of undesirable corona.

The **Division of Tribophysics, Commonwealth Scientific and Industrial Research Organization,** East Melbourne, Australia, has moved into a new building on the grounds of the University of Melbourne. The Division was started during the war to assist with purely practical problems arising from wartime engineering difficulties. However, it has become a recognized authority on certain aspects of lubrication and bearing design, and has given a good deal of advice

to industry. Also, since surprisingly little is known about what happens when metals are subjected to such operations as cutting, rolling, pressing, and extruding, much of the Division's work lies in this field, and the new building has been designed and equipped with this in mind.

Grants, Fellowships, and Awards

The Nebraska Academy of Sciences has awarded the **1952 AAAS Research Grant** to R. C. Lommasson of the Department of Botany, University of Nebraska, for his research project on the measurements of internal tissues of cereals.

The Commonwealth Fund annual report lists the following research grants for 1953 (for British and "Salzburg" fellowships, see SCIENCE **118**, 178):

University of Alabama. R. J. Bing, Medical College of Alabama. Physiological studies of the heart and circulation.
University of California. H. W. Magoun, School of Medicine. Study of functional interrelationships between the brain stem and cerebral cortex.
University of Chicago. I. Gersh. Histochemical studies of the submicroscopic organization of cells and of extracellular substances.
University of Chicago. H. Klüver. Study of the porphyrins.
University of Colorado School of Medicine. A. H. Washburn, Child Research Council. Study of growth and development.
Cornell University Medical College. M. G. Wilson, New York Hospital. Study of rheumatic fever.
Harvard Medical School. W. Bauer, Massachusetts General Hospital. Study of arthritis.
Harvard Medical School. F. Lipmann, Massachusetts General Hospital. Studies of cellular metabolism.
Harvard Medical School. N. B. Talbot, Massachusetts General Hospital. Pediatric endocrinological studies.
Harvard Medical School. M. D. Altschule, McLean Hospital. Physiological studies of the pineal gland, with particular reference to the psychoses.
Harvard Medical School. D. Hume, Peter Bent Brigham Hospital. Study of the control of pituitary function.
Harvard University. A. Weinstein. Genetic studies of the mechanism of crossing over.
New York University. H. Teuber, College of Medicine. Studies of cerebral function.
New York University. R. Chambers. Synthesis of studies of the living cell.
University of Pennsylvania School of Medicine. T. N. Harris, Children's Hospital. Study of the mechanism of antibody formation.
University of Pennsylvania School of Medicine. S. S. Cohen, Children's Hospital. Chemical studies of virus formation.
University of Pennsylvania School of Medicine. M. B. Lurie, Henry Phipps Institute. Studies of resistance and susceptibility to experimental tuberculosis.
Tulane University. R. G. Heath, School of Medicine. Studies of schizophrenia.
Washington University. P. Heinbecker and C. A. Moyer, School of Medicine. Studies of physiological controls centering in the pituitary gland.
Yale University. M. J. E. Senn, Child Study Center. Study of emotional development in early childhood.

Advanced Fellowships in Medicine and Allied Fields

P. W. Guilbert, University of Montreal Faculty of Medicine. Nutritional research, Dept. of Pediatrics, Univ. of Pennsylvania School of Medicine, 2 yrs.
G. B. Odell, Yale University School of Medicine. Metabolic disorders in children, Dept. of Experimental Medicine, Univ. of Cambridge, 1 yr.
S. Reichlin, Washington University School of Medicine. Neuro-endocrinology, Institute of Psychiatry, University of London, 2 yrs.
M. W. Spellman, Howard University College of Medicine. Third year of surgical training, University of Minnesota Medical School.
P. K. Munter, Columbia University College of Physicians and Surgeons. Psychiatry, Massachusetts Institute of Technology, 1 yr.
J. Cumming, University of Toronto Faculty of Medicine. Community health problems, Dept. of Social Relations, Harvard University, 2 yrs.
R. L. Gilmer, Stuart Circle Hospital School of Nursing. Advanced psychiatric nursing, Columbia and Maryland universities, 1 yr.
G. Lindzey, Harvard University. Didactic psychoanalysis, Boston Psychoanalytic Institute.
R. T. Scholes, University of Rochester School of Medicine. Sociological and anthropological factors of health problems, University of Chicago, 6 mos.
E. G. Dreyfus, Harvard Medical School. Public health and social science, Dept. of Social Relations and School of Public Health, Harvard University, 1 yr.

The **Damon Runyon Memorial Fund** made the following research grants during November:

Institut Jules Bordet, Brussels, Belgium. H. J. Tagnon. Cancer research, $10,000.
Hospital de Enfermedades de la Nutricion, Mexico. G. Montano. $5000.
Cancer Society of Finland. Cancer research, $5000.
University of Rochester. D. S. Tarbell. Carcinogenic action of 3,4-benzpyrene, $7500.
Mount Zion Hospital, San Francisco. B. L. Freedlander. Chemotherapy of experimental mouse tumors, $7400.
Ohio State University. C. A. Doan. Investigations on urinary adrenocorticosteroids, $4500.
Jefferson Medical College. C. W. Wirts. Gastric cancer detection studies, $5000.
J. Heyman, Radiumhemmet, Sweden. Annual report on the results of treatment of carcinoma of the uterus, $1000.
International Congress of Clinical Pathology. Support of third congress, $2500.
National Committee of the International Union Against Cancer. To sponsor representatives to VIth Congress in Brazil, $3000.
Columbia University. G. Godman. Renewal fellowship, $4200.

The General Electric Company, for the eighth consecutive year, will offer 50 preparatory and high school physics teachers from north central states, a special 6-week study program at Case Institute of Technology. Teachers from the following states may apply: Illinois, Indiana, Iowa, Kentucky, Michigan, Missouri, Minnesota, Ohio, Western Pennsylvania, Tennessee, West Virginia, and Wisconsin.

Applicants for **General Electric Science Fellowships** must be college graduates, must possess experience in preparatory or high school science teaching, and must be certified to teach in their respective states.

The all-expense fellowship program will run from June 20 to July 30, 1954. Fellowship funds will cover living expenses on the Case Tech campus, books, tuition, fees, and travelling expenses to and from Cleveland.

The University of Wisconsin invites professors to nominate from among their students in the natural sciences, including engineering, young men and women of unusual ability as candidates for the **Wisconsin Alumni Research Foundation Assistantships.** These awards carry a stipend of $1500 for the period July 1, 1954, to June 30, 1955, with one month vacation; in special cases, awards will be made for the academic year with compensation of $1250 for this shorter period. In addition to the salary, recipients of these awards are exempt from payment of the non-resident tuition of $320 for the year, but are required to pay the general fee of $90 per semester required of all

students. The assistantships are renewable for a second year.

Recipients of these awards are free to select their research problem in consultation with their major professors. They will, of course, be registered in the Graduate School and will receive full residence credit toward the graduate degree. Candidates in chemistry who wish to be considered for appointment in other fields that make extensive use of chemistry, such as bacteriology, biochemistry, botany, physiology, pharmacology, soils, and zoology, are requested to give their alternative choice in filling out the application blank. For graduate work beginning June 28 or Sept. 20, 1954, *applications should be received by Feb. 15, 1954.*

Meetings and Elections

The **American Association of Colleges of Pharmacy** has elected the following officers for 1953–54: pres., Edward C. Reif, University of Pittsburgh; pres.-elect, Joseph B. Burt, University of Nebraska; v. pres., Kenneth L. Waters, University of Georgia; chairman of executive committee, Louis C. Zopf, State University of Iowa; sec.-treas., Richard A. Deno, University of Michigan.

The **American Academy for Cerebral Palsy** has elected the following officers for 1954: pres., Meyer A. Perlstein, Chicago, Ill.; pres.-elect., Lenox D. Baker, Durham, N.C.; sec.-treas., Harry E. Barnett, Chicago, Ill.

The **American Institute of Chemical Engineers** has elected the following officers for 1954: president, Chalmer G. Kirkbride, Houdry Process Corp., Philadelphia, Pa.; v. pres., Barnett F. Dodge, Yale University; treas., George Granger Brown, University of Michigan; sec., Stephen L. Tyler.

Officers for the **American Medical Writers' Association** for 1954 are: pres.-elect, Lee van Antwerp, Chicago, Ill.: 1st v. pres., W. W. Bauer, Chicago, Ill.; 2nd v. pres., Stewart Wolf, Oklahoma City, Okla.; sec.-treas., Harold Swanberg, Quincy, Ill. The president for 1954, elected last year, is Jacob E. Reisch, Springfield, Ill.

The **American Society for Professional Biologists** has elected the following officers for 1954: pres., John M. Hale; pres.-elect., Austin W. Morrill, Jr.; treas., Ronald N. Wood. The new vice presidents are John R. Walker, Stefan Ansbacher, Dale Lindsay, and George Foley.

The **Botanical Society of America** has elected the following officers for 1954: pres., Adriance S. Foster, University of California; v. pres., Oswald Tippo, University of Illinois; treas., Harry J. Fuller, University of Illinois; sec., Harriet B. Creighton, Wellesley College.

The **Committee for the Scientific Study of Religion** held its fall meeting at Harvard University on Nov. 21. A program of papers in the fields of anthropology, psychology, and sociology was presented. The next meeting was set for April 10 in New York. Social scientists with empirical research to report in the area of religion should submit, *by Feb. 15,* three copies of an abstract, not over three hundred words, to Dr. David Barry, National Council of Churches, 297 4th Ave., New York 10. For membership information write the secretary, Dean W. H. Clark, Hartford School of Religious Education, Hartford 5, Conn.

Initial steps have been taken for the formation of the **National Pharmaceutical Council, Inc.** The founding group of the new organization met in Atlantic City on Dec. 1–2, 1953. The announced purposes of the Council are:

To benefit public interest by promoting the highest professional standards in the manufacture, distribution, and dispensing of prescription medication and other pharmaceutical products.

To benefit the pharmaceutical industry by promoting public relations programs on behalf of pharmacists and others in the industry.

To promote the interests of the public, physicians, pharmacists, and others in the pharmaceutical industry by encouraging the highest standards of ethics and integrity in the manufacture, distribution, and dispensing of prescription medication and other pharmaceutical products.

To collect and disseminate information concerning laws, regulations, and governmental agencies dealing with the manufacture, distribution, and dispensing of prescription medication and other pharmaceutical products as a contribution to the better understanding thereof in the public interest.

Member companies in the new organization are: Abbott Laboratories; Ciba Pharmaceutical Products, Inc.; Hoffmann-LaRoche, Inc.; Lederle Laboratories; McNeil Laboratories, Inc.; The William S. Merrell Co.; Pfizer Laboratories (& J. B. Roerig & Co.); G. D. Searle & Co.; Smith, Kline & French Laboratories; E. R. Squibb & Sons; The Upjohn Co.; and Winthrop-Stearns, Inc.

Theodore G. Klumpp was elected president, and the vice presidents are L. J. Barrett, Franklin P. O'Brien, O. J. May, and Henry Wendt, Jr. John Bradley and L. J. Sichel are secretary and treasurer, respectively.

A Symposium on Orthopteran Acoustics will be held April 5–8, 1954, at the Laboratoire de Physiologie Acoustique de l'Institut National de la Recherche Agronomique, Jouy-en Josas (Seine & Oise), France. Certain specialists have been asked to act as reviewers and give general expositions, notably: for Germany, H. Autrum, University of Würzburg and W. Jacobs, University of Munich; for England, R. J. Pumphrey, University of Liverpool; for Italy, E. Benedetti, University of Parma; for the United States, H. Frings, Pennsylvania State College. Inquiries should be addressed to the Laboratoire de Physiologie Acoustique.

Miscellaneous

The urgent need by official agencies for scientific information on disaster problems and the opportunity to foster basic scientific work in a variety of fields have caused the National Academy of Sciences—National Research Council to set up a Committee on Disaster Studies under the Council's Division of Anthropology and Psychology. Because of the increasing interest in disaster research, the many disciplines involved, and the great need for exchange of information in this field, the Committee has established a **Clearinghouse for Disaster Studies.** The Committee would like to receive available reprints and reports, especially unpublished reports, on disaster studies, or related research, and would appreciate communication with the investigators of any "in-progress" studies. The Clearinghouse will then be able to make available a currently useful reference source. Information should be directed to the Committee on Disaster Studies, National Academy of Sciences, 2101 Constitution Ave., Washington 25, D.C.

The following **chemicals** are wanted by the **Registry** of Rare Chemicals, Armour Research Foundation of Illinois Institute of Technology, 35 W. 33 St., Chicago, Ill., 16: N-methyl-6(1)-pyridone-3-carboxamide; 2,1,3,4-tetrazole-5-carboxylic acid; cis-diphenylethylene oxide; 4-methoxyproline; 1-methylxanthine; capsaicin; cinchol; kynurenine; L-limonene; gymnemic acid; 6-methylindole; 1,4-dibromo-2-butyne; 3,5-dihydroxycinnamic acid; pyrazine-2,3-dicarboxylic acid; 4-methyltryptophane; glycyrrhetinic acid; amygdalin; delta-tocopherol; ornithuric acid; and protoanemonin.

At its 1952 meeting in Rome, the International Astronomical Union undertook the project of issuing a revision of ***Astronomical Observatories and Astronomers,*** the last edition of which came out in 1936. This publication lists official observatories, astronomical societies, and periodicals dealing with astronomy. As in the past, the Royal Observatory of Belgium will assume the editorial work. At present it is distributing questionnaires. All astronomical institutions that have not received the questionnaire by Jan. 1, 1954, should request one from the Observatoire Royal, Uccle-Bruxelles, Belgium.

Necrology

Augustine J. Annunziata, 54, head of the Pediatrics Department of Mother Cabrini Hospital, New York, N.Y., Nov. 19; **Sir Lancelot Barrington-Ward,** 69, surgeon, London, England, Nov. 17; **E. Bataillon,** 85, experimental embryologist and professor emeritus of zoology, University of Montpellier, France, Nov. 1; **Carl E. Buck,** 62, professor of public health at the University of Michigan School of Public Health, Ann Arbor, Mich., Nov. 21; **George P. Burns,** 82, professor emeritus and former chairman of the Department of Botany, University of Vermont, Burlington, Vt., Nov. 14; **Edward H. Cary,** 81, former president of the American Medical Association and dean of the Baylor Medical School, Houston, Tex., Dec. 11; **Paul S. Clapp,** 63, retired electrical research engineer, New York, N.Y., Dec. 5; **Clarence E. Earle,** 60, inventor and former chief of the Chemical Research and Development Section, Bureau of Aeronautics, Washington, D.C., Nov. 25.

K. George Falk, 73, biological chemist, public health aide, author, and president of the Hebrew Technical Institute, New York, N.Y., Nov. 22; **P. W. Fattig,** 72, entomologist and curator of the Emory University Museum, Atlanta, Ga., Dec. 7; **Walter K. Fisher,** 75, professor emeritus of zoology and former director of Hopkins Marine Station, Stanford University, Pacific Grove, California, Nov. 2; **Edward M. Frankel,** 60, research chemist and chemical engineer, New York, N.Y., Nov. 19; **M. I. Graves,** 86, internist and former president of the Texas Medical Association, Houston, Tex., Nov. 19; **Harry C. Guess,** 65, faculty member at the University of Buffalo Medical School, Buffalo, N.Y., Dec. 2; **Herbert E. Ives,** 71, electron-optical scientist, developer of 3-D photography, wirephoto transmission, and television, and former vice president of AAAS, Upper Montclair, N.J., Nov. 13; **James H. King,** 61, marine engineer and former president of the Society of Naval Architects and Marine Engineers, Scarsdale, N.Y., Nov. 14; **Stephen W. McClave, Jr.,** 72, engineer, Englewood, N.J., Nov. 24; **Wilfred G. McConnel,** 84, retired civil engineer, Stamford, Conn., Nov. 21; **Charles F. Menninger,** 91, psychiatrist, founder of the Menninger Clinic, Topeka, Kans., Nov. 28; **J. Hillis Miller,** 54, former professor of psychology and president of the University of Florida, Gainesville, Fla., Nov. 14.

Elsie B. Naumburg, 73, ornithologist and staff member at the American Museum of Natural History, New York, N.Y., Nov. 26; **George E. Partridge,** 83, psychologist and former lecturer at Clark University, Worcester, Mass., Nov. 16; **Stefan Pienkovsky,** chief of atomic research in Poland, Warsaw, Nov. 21; **Frank H. Pike,** 79, neurologist, former professor, and lecturer at the College of Physicians and Surgeons, Columbia University, New York, N.Y., Nov. 13; **George Rosengarten,** 66, professor of physics and mathematics at the Philadelphia College of Pharmacy and Science, Philadelphia, Pa., Nov. 23; **Conley H. Sanford,** 60, professor and chief of the Division of Medicine of the University of Tennessee College of Medicine, Memphis, Tenn., Nov. 16; **Reed A. Shank,** 61, surgeon and former faculty member of the University of Cincinnati College of Medicine, Nov. 26; **Timothy W. Stanton,** 93, former professor and retired chief geologist of the United States Geological Survey, Washington, D.C., Dec. 4; **Harold A. Titcomb,** 78, consulting and mining engineer, Farmington, Me., Nov. 26; **Oldrich Tomicek,** 62, professor of analytical chemistry at the University of Prague, Czechoslovakia, Oct. 21; **Philip W. Woods,** 45, dental consultant for the Welfare and Retirement Fund of the United Mine Workers of America, Takoma Park, Md., Dec. 10; **Pope Yeatman,** 92, mining engineer, Philadelphia, Pa., Dec. 5.

Technical Papers

The Relative Biological Effectiveness of Radiation from a Nuclear Detonation on *Tradescantia* Chromosomes[1]

Alan D. Conger[2]

Biology Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee

The ionizing radiations emitted from a nuclear detonation are additional biological hazards that exist over and above the usual ones of blast effects from ordinary explosions. Although much was known about the biological effects of the various types of radiation when they are given singly in the laboratory, there was good reason to suspect that the biological effect might be greater when these radiations are emitted as a mixture of all types and energies and at extremely high intensity, as they are from a nuclear detonation. So, prior to the planned biological experiments at nuclear detonations, there was genuine cause for uncertainty about how much damage could be expected.

For the resolution of these problems, certain conditions must be met. In the first place, it is not enough merely to expose living material to nuclear radiation and then observe that it is affected—this tells nothing not already known. Neither is it enough to measure quantitatively how much living material is affected unless, in the future, biological materials prove to be as easy to handle and as commonly available as are physical dosimeters. It is necessary to know the quantitative relation between dose and biological effect of the radiation, and also how this compares with the dose-effect relation of the same radiations, delivered by the usual laboratory sources. With this knowledge, the large background of laboratory radiation experience can be applied to the nuclear detonation results. This means that there must be dose measurements (i.e., by physical instruments) and biological measurements of effect for both laboratory and nuclear radiations, and that the usefulness of the biological data for conclusions about the biological damage of nuclear radiation will be dependent on the accuracy of measurement by these two, physical and biological, instruments. These remarks will explain the necessity for the marked preoccupation in this and the following "biological" papers on the relation of physical measurements to the biological effects observed.

The flowering plant *Tradescantia* was an obvious choice for experimentation of this sort, since a fundamental effect of radiation on all cells, chromosomal aberrations resulting from chromosome breaks, can be quantitatively measured in it, and its response under different radiative and environmental conditions was already well known. Lea (*1*) and Catcheside (*2*) give complete presentations of *Tradescantia* methods, experimental data, and theory.

At an early nuclear test operation it was proposed to expose *Tradescantia* to the nuclear radiation, but excluding blast and thermal effects, in three different situations, namely, (1) to the mixed radiation experienced inside an airplane flown through an atomic cloud (the "mushroom") at various altitudes, (2) to essentially pure gamma rays, inside thin protective

TABLE 1. Irradiation conditions in three control experiments.

The control experiments are designed to simulate field conditions of: (1) gamma rays—flash exposures of different total doses; (2) fast neutrons—at high intensities; (3) airplane exposures—to mixed radiation in an atomic cloud at 0.4° C and 380 mm Hg pressure.

Experiment	Type of radiation	Intensity	Measured by (accuracy)	Conditions (temp., pressure)
(1) Gamma ray	Hard x-rays 250 kvp, 30 ma; ½ mm Cu, 3 mm Al filters	650 r/min and 504 r/min	Victoreen r-meter (±3%)	n.t.p 24° C
(2) Fast neutrons	Fast neutrons from uranium fission 4 Mev maximum, 1 Mev average	3.4 n units/min	Victoreen r-meter (±20%)	n.t.p 25° C
(3) Airplane	Gamma rays from Co^{60}	4.6 r/min	Gamma-ray thimble ionization chamber (±1%) (*4*)	+0.4° C, 380 mm Hg pressure for 10 min before, during, and 10 min after exposure

[1] Work performed under Contract No. W-7405-Eng-26 for the Atomic Energy Commission.

[2] It is difficult to acknowledge all the individuals who have contributed in programs related to this one. Dorin S. Daniels and Lucile M. Fairchild did much of the *Tradescantia* work, the former at both Oak Ridge and the test site. Allyn W. Kimball and George Atta developed and applied the statistical analysis used throughout. Charles W. Sheppard advised and very generously helped from beginning to end. The author particularly wishes to acknowledge his indebtedness to Robert E. Carter whose efforts were responsible for many of the facilities and much of the information that was used in common by all the other biological investigators.

containers (gamma-ray stations), at increasing distances along the ground from the nuclear device, and (3) to mostly fast neutron radiation received inside special 7-in.-thick lead hemispheres (neutron stations), placed along the ground closer to the nuclear device than the gamma-ray containers. Physical instruments of various kinds were placed along with the *Tradescantia* and other living material in these three different situations.

Prior to the tests, *Tradescantia* was irradiated at

TABLE 2. Gamma-ray control experiment.
X-rays, 250 kvp, 30 ma, ½ mm Cu + 3 mm Al
Irradiated in resting stage; chromosome aberrations observed 4 days later

Dose (r)	No. of buds	No. of cells	Fraction normal cells	Aberrations per cell	
				Exchanges	Deletions
Intensity, 605 r/min					
27	7	1301	0.96	0.014	0.028
54	6	868	0.93	0.024	0.053
108	8	650	0.78	0.11	0.13
217	7	650	0.50	0.24	0.39
433	7	317	0.08	0.90	1.44
Intensity, 504 r/min					
50	9	850	0.90	0.032	0.074
101	6	592	0.79	0.12	0.14
151	4	317	0.68	0.17	0.23
202	8	549	0.53	0.28	0.34
403	5	250	0.08	0.89	1.12
605	8	400	0.005	1.50	2.25

TABLE 3. Fast neutron control experiment.
Fast neutrons from uranium fission, 4 Mev maximum, average 1 Mev 3.1 n units/min
Irradiated in resting stage; chromosome aberrations observed 4 days later

Dose (n units)	No. of buds	No. of cells	Fraction normal cells	Aberrations per cell	
				Exchanges	Deletions
4	6	650	0.67	0.16	0.25
8.1	1	100	0.47	0.32	0.49
16.2	4	150	0.21	0.66	0.80
24.2	5	249	0.11	0.85	1.31
32.4	3	150	0.05	1.18	1.65

Oak Ridge in a series of control experiments designed to simulate as closely as possible the conditions anticipated in the three different nuclear test irradiation situations just mentioned. The irradiation conditions for these control experiments are given in Table 1 and the biological results in the succeeding Tables 2, 3, and 4. It is important to mention that the usefulness of the control data is dependent on how closely the (pertinent) control conditions actually simulated the test conditions. Proper simulation was achieved in all cases but one, but fortunately there were data which were independent of the particular variable which differed between test and control.

TABLE 4. Airplane control experiment.
Co^{60} gamma rays at 0.4° C, pressure of 380 mm Hg, 4.6 r/min
Irradiated in prophase; chromatid aberrations observed 21–24 hours later

Dose (r)	No. of buds	No. of cells	Fraction normal cells	Aberrations: One-hit types: Chromatid no.	Isochromatid no.	Cd. + Isocd. per cell	Cd./Cd. interchanges per cell
25	4	187	0.82	19	9	0.15	0.032
50	10	853	0.69	127	118	0.29	0.057
100	6	429	0.42	146	142	0.67	0.10
200	6	275	0.13	190	156	1.26	0.42

For these tests, two things are observed, biological effect and physical dose from both the test radiation, and, since we desire also to know how the nuclear detonation compares with laboratory experience, from laboratory radiation. From the test exposures, it is desired to estimate biologically the unknown radiation dose x' received at a station from the observed aberration frequency y' caused by it. This estimate is made by using the data from the appropriate control experiment in which the aberration frequency y caused by a known dose x of the same radiation has been measured. Aberration frequency is related to ionization dose as $y = a + bx$ for the "one-hit" aberrations, and $y = d + ex + fx^2$ for the "two-hit" or exchange aberrations, which for more accurate statistical treatment is expressed as $\sqrt{y} = a' + b'x$.

The solutions of these equations, by least-squares fits to the data from control experiments in Tables 2, 3, and 4, is given in Table 5. It can be seen that changes in the type of radiation and in the environmental conditions during irradiation have a pronounced effect on the yield of aberrations from a given dose.

The point estimate of nuclear radiation dose x' received at any one station is

$$x' = \frac{y' - a}{b} \quad \text{(for linear cases)}$$

and

$$x' = \frac{\sqrt{y'} - a'}{b'} \quad \text{(for quadratic cases).}$$

The confidence intervals for the dose estimates may be obtained with a straightforward application of a method described by Mood (*3*).

Airplanes. The biological results and dose estimates from the airplane exposures are given in Table 6. It will be noticed that the dose estimates from the essentially "one-hit" (chromatid plus isochromatid deletions) and the "two hit" or interchange aberrations, both of which are from the same population of cells, differ from each other. This is because the radiation intensity differed among the various airplanes, and also from the control experiment. In this case, it is

TABLE 5. Regression equations to the control data from least-squares fits.

Type of radiation, for comparison	Control experiment table	Chromatid or chromosome observations	Type of aberration	$y = a + bx$ or $\sqrt{y} = a' + b'x$		
				y	a	b
X-rays at high intensity; for gamma-ray	2	Chromosome	Exchanges	$\sqrt{y}$	0.101	0.00194
station	2	Chromosome	Deletions	$\sqrt{y}$	0.122	0.00234
Fast neutrons; for neutron hemispheres	3	Chromosome	Exchanges	y	0.0373	0.0351
(n units)	3	Chromosome	Deletions	y	0.0577	0.0496
Gamma rays at 0.4° C and 380 mm Hg	4	Chromatid	One hit	y	−0.00783	0.00640
pressure; for airplanes (r)	4	Chromatid	Interchanges	$\sqrt{y}$	0.0947	0.00268

TABLE 6. Biological observations and dose estimates in airplanes. Chromatid aberrations observed 21–24 hr after irradiation.

Airplane	Biological observations					Dose estimates (r) and 90% confidence intervals			
						From Cd. + Isocd.		From interchanges	
	No. of buds	No. of cells	Fraction normal cells	Cd. + Isocd. per cell	Cd./Cd. interchanges per cell	Dose est.	90% conf.	Dose est.	90% conf.
a	6	303	0.34	0.74	0.17	117	101–133	120	74–171
b	9	332	0.48	0.45	0.17	71	54–87	118	75–167
c	2	106	0.49	0.49	0.23	78	61–93	142	97–195
d	12	475	0.78	0.21	0.02	34	16–51	19	0–66
e	13	371	0.57	0.46	0.07	73	56–89	66	14–112
f	5	205	0.18	1.13	0.30	178	160–196	170	124–232
g	8	236	0.94	0.05	0.004	8	0–26	—	—
h	14	317	0.92	0.07	0.003	12	0–30	—	—
i	11	238	0.91	0.09	0	16	0–33	—	—

justified to ignore the results from the intensity-dependent interchange aberrations and to utilize only the intensity-independent "one-hit" aberrations, thus eliminating the one variable, intensity, known to differ in the control and the test exposures. In this way the results given in Table 7 are obtained. In this table

TABLE 7. Dose measurements in airplanes by *Tradescantia* and NBS film packs (roentgens).

Airplane	*Tradescantia*	Film
a	117	112 and 104
b	71	66 and 62
c	78	80 and 84.5
d	34	35.5
e	73	54
f	178	135
g	8	4.5
h	12	11
i	16	18

are compared the dose estimates from *Tradescantia*, by one-hit (chromatid-plus-isochromatid) aberrations, and the dose measurements by National Bureau of Standards film packs which were exposed with the *Tradescantia*. It can be seen the agreement between measurements of dose by the film packs and by *Tradescantia* is quite good.

The yield of chromatid-plus-isochromatid (one-hit) aberrations from the airplanes is plotted against dose measurements by the NBS film packs in Fig. 1. The plotted line is the yield of these same aberrations against dose from the control experiment (Table 5, the least-squares fit). It will be seen that the dose esti-

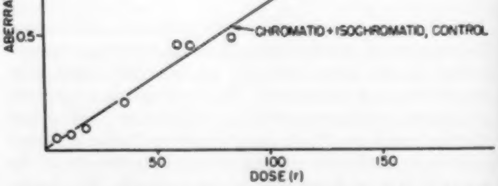

FIG. 1. Production of chromosomal aberrations inside airplanes flown through an atomic cloud, and by control radiation in the laboratory. ○, chromatid plus isochromatid aberrations vs. dose (r) measured by NBS film packs in airplanes. ———, same aberrations vs. dose (r) of Co^{60} gamma rays from laboratory control experiment.

mates from the aberration frequency points can be obtained visually by striking off their intersects with the control curve, and reading the dose off the abscissa. The fit of the *Tradescantia* aberration yields from the airplanes to the control curve against dose is dependent on: (1) the accuracy of the dose measurements in the control experiments, (2) the accuracy of the dose measurements by the NBS film packs exposed in the airplanes with the *Tradescantia,* and finally, (3) the equality or nonequality of *Tradescantia* response to control and nuclear radiation. Dose measurements in the control experiment are accurate to ±1%, or ±5% at the very worst. The film packs are probably accurate in most cases to *ca.* ±10%, since the radiation received inside the airplanes was mostly gamma rays plus a small amount of hard beta rays. This amounted to good conditions for these instruments. With the dosimetry thus properly resolved it can now be determined if *Tradescantia* responds equally to control and nuclear test radiation. It is obvious from the graph that it does, for at most doses the aberration yield falls on or almost on the control line curve. If the airplane radiation were, for example, more effective than the control, the points should all fall uniformly above the control line. The worst case, at the highest dose is only 24% off the line, and in this airplane other biological measurements also departed from the films in the same direction, suggesting that this particular measurement may have been in error. The others deviate by only 10% or less.

Taking all the data, it can be said that the radiation received inside an airplane from an atomic cloud has a relative biological efficiency (RBE) to Co^{60} gamma rays of about 1, and this is accurate to about 20%, perhaps less. Mice which were exposed with *Tradescantia* gave about the same result. The physical instruments are therefore reliable indicators of the amount of biological damage that will be caused, and physical measurements plus laboratory experience will predict the radiobiological effect caused in airplanes flown through atomic clouds.

Gamma Rays. The second situation investigated was the effect of gamma rays at increasing distances along the ground from the nuclear device. *Tradescantia* and mice were exposed at a number of gamma-ray stations along with ionization chambers and film packs both inside and outside the exposure containers. The results are given in Table 8. It is seen that for most stations the dose estimates from "deletions" (chromosome terminal deletions plus minutes) are lower than the estimates from "exchanges" (chromosome dicentrics plus rings). It is common experience that when slide preparations are poor (as were those from the test exposures) fewer deletions are observed than when slides are good. This is understandable, for most of these deletions are small dot fragments which can escape microscopic observation in poor preparations. The slides from the nuclear tests were much poorer than those obtained from the control experiments, which probably accounts for the low dose estimates from deletions. Fortunately, exchanges are large aberrations which are seen equally well in poor or good slide preparations and are therefore the suitable ones for the control-test comparisons.

TABLE 8. Biological observations and dose estimates in gamma-ray stations. Chromosome aberrations observed 4 days after irradiation.

Station	Biological observations					Dose estimates (r) and 90% confidence intervals				Physical dose (r) from least-squares curves	
						From deletions		From exchanges			
	No. of buds	No. of cells	Fraction normal cells	Deletions per cell	Exchanges per cell	Dose est.	90% conf.	Dose est.	90% conf.	NBS film packs, outside	Ionization chambers, inside
a	3	44	0.52	0.34	0.27	197	158–237	217	174–260	210	175
b	10	202	0.41	0.42	0.44	224	184–263	290	248–334	315	270
c	4	191	0.12	0.83	1.03	337	298–377	462	417–509	470	415
d	6	97	0.03	1.20	1.38	416	376–455	554	507–604	615	550
e	1	34	0	3.18	1.97	710	670–751	672	621–727	750	680

To avoid the difficulty of dealing with a curvilinear relation, since the exchange aberrations being considered increase quadratically with dose of x or gamma rays, we have plotted in Fig. 2 the linear relation, square root of exchange aberration yield against dose, measured by ionization chambers and films in the gamma-ray stations. The solid line is square root of exchange aberration yield against dose from the least-squares fit to the control data, Table 5. The experimental points are from the test measurements, Table 8.

In these gamma-ray stations, unlike the airplanes, there is a definite relation between the doses at the different stations, which were at increasing and known distances away from the nuclear device. So, for both the aberration yield and dose data we have not only the experimental measurements at each station, but the curves of least-squares fits to the measurements over the whole range of doses experienced. Comparison of these curves gives much more reliable information than the individual points, and is indicated by the two lines "exchanges vs. film dose" and "exchanges vs. ionization chamber dose."

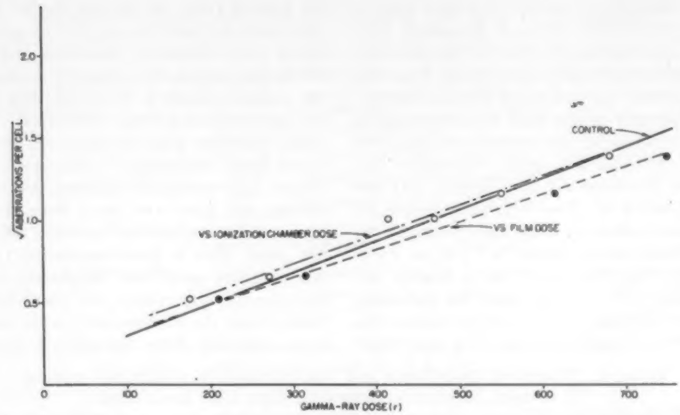

FIG. 2. Production of chromosome aberrations by nuclear gamma rays, and by control radiation in the laboratory. — — —, ● $\sqrt{\text{aberrations per cell}}$ vs. nuclear gamma ray dose (r) measured by NBS film packs. —·—·—, ○ same, measured by ionization. Chamber dose. ——— same, vs. dose (r) of hard x-rays from laboratory control experiment.

Inspection of the graph shows that the nuclear gamma rays are just about as effective as the control radiation (hard x-rays) in causing *Tradescantia* chromosomal aberrations, whether the test dose is measured by ionization chambers or by films. Actually, taking the very worst cases at the two extremes of greatest divergence, the films would indicate that nuclear gamma rays are 10% less effective than the control radiation (at the highest dose), the ionization chambers would show them to be 18% more effective than control radiation (at the lowest dose). From the careful work of Kirby-Smith and Daniels (*4*) on the RBE of x-rays to Co^{60} gamma rays in causing *Tradescantia* aberrations, this would indicate that the quality of these test gamma rays was about that of the hard x-rays used for the control experiments. This is approximately true; the long traverse through air and the ground scattering had degraded the gamma-ray energy considerably, practically down to the range of x-ray energy. But over the whole range of doses measured, these curves differ from one another by only about 10%. It can thus be stated that nuclear gamma rays and the control radiation, hard x-rays, produce equal biological effects, i.e., the RBE of nuclear gamma rays to hard x-rays is $1 \pm 20\%$.

Fast Neutron Stations. Tradescantia and mice were exposed to fast neutrons inside special lead containers placed at closer distances to the nuclear device than the gamma-ray containers. The above-ground part of a neutron container was a lead hemisphere with 7-in.-thick lead walls, and a central cavity 14 in. in diameter containing the specimens. The intent was that the 7 in. of lead should be opaque to the external gamma rays but transparent to neutrons.

The *Tradescantia* results from the fast neutron lead hemisphere stations are given in Table 9. It is apparent that the dose estimates from deletions are variable, as was true for the gamma-ray stations and probably for the reasons already given, so only the more reliable data from chromosome exchanges will be considered.

Unfortunately, the only physical measurements made at these stations which are pertinent to our purpose will show only the relative doses received at the different stations. What was measured was the number

TABLE 9. Biological observations and dose estimates in neutron hemisphere stations. Chromosome aberrations observed 4 days after irradiation.

Test Station		Biological observations					Dose estimates (n units) and 90% confidence intervals			
							From deletions		From exchanges	
		No. of buds	No. of cells	Fraction normal cell	Deletions per cell	Exchanges per cell	Dose est.	90% Conf.	Dose est.	90% conf.
A	a	4	97	0.54	0.35	0.25	5.9	2.9– 8.7	6.0	2.7– 9.0
	b	2	116	0.24	0.64	0.63	11.7	9.0–14.4	16.8	13.9–19.7
	c	5	176	0.03	2.00	1.15	39.2	35.8–43.0	31.6	28.5–35.2
B	d	9	253	0.50	0.29	0.39	4.7	1.7– 7.5	10.0	6.8–12.8
	e	13	550	0.08	1.08	1.00	20.7	18.1–23.4	27.5	24.5–30.8
	f	7	210	0.005	2.62	1.72	51.8	47.6–56.5	47.9	44.0–52.6
	g	2	64	0	3.62	2.20	71.8	66.1–78.7	61.6	56.2–68.0

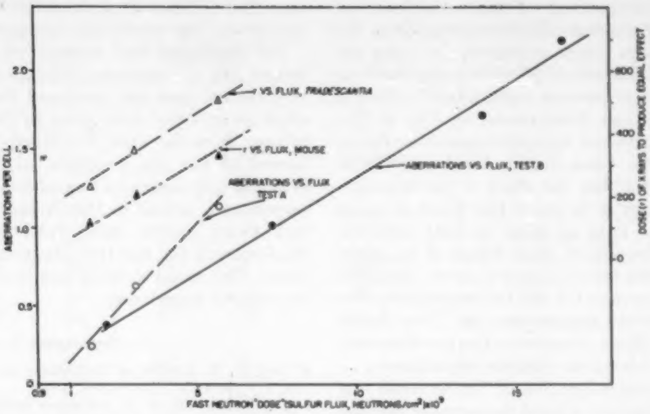

FIG. 3. Effect of nuclear fast neutron radiation on *Tradescantia* and on mice. ○, ● aberrations per cell vs. neutron "dose" (sulfur flux) on tests A and B. Read from left ordinate scale. — — —, △ Dose (r) of laboratory hard x-rays which would cause an equal number of aberrations as was found on test A. Read from right ordinate scale. —·—·—, ▲ Dose (r) of laboratory hard x-rays which would cause an equal effect on mice as was found on test A.

of neutrons (of energy greater than 3 Mev) per square centimeter received at positions outside the hemispheres, the so-called sulfur flux. Although this sulfur flux is proportional to the dose received by the material inside the hemispheres, any conversion of it to inner biological dose is subject to prohibitive errors and assumptions; it is, however, useful for prediction of biological effect as a function of distance and of other variables. The complication that may be caused by any (unknown) dependence of effect on neutron energy spectrum is believed to be minimized by emperical simulation of test conditions in the control experiments which were made with uranium fission neutrons transmitted through 4 in. of lead. The increase of chromosome exchanges with relative neutron "dose" is shown for two different tests in Fig. 3. Since dose is in relative units, the only conclusion that can be made is that biological effect increases linearly with dose, which is as it should be if the radiation were neutrons, or mostly neutrons. Had the radiation been gamma rays, the effect would have increased quadratically with dose. No comparisons with the control data, such as were made for the airplanes and gamma-ray stations, are possible.

To derive other information, it is necessary that dosimeters be measured in the same units. Fortunately, this is possible for two of the dosimeters exposed together in the hemispheres. The dosimeters were biological, mice and *Tradescantia*, and the readings were in terms of biological effect, thymus weight loss for the mice and chromosome aberrations for *Tradescantia*. Since the two were exposed together,

TABLE 10. Specific control experiments at test site.

Treatment (radiation)	Biological observations: No. of buds	No. of cells	Fraction normal cells	Chromosome deletions per cell	Chromosome exchanges per cell	Dose estimates (r) and 90% confidence intervals: From deletions: Dose est.	From deletions: 90% conf.	From exchanges: Dose est.	From exchanges: 90% conf.
None*	7	483	0.993	0.008	0	—		—	
Specific control† (in neutron stations)	2	313	1.00	0	0	—		—	
Specific control† (gamma-ray stations)	2	183	1.00	0	0	—		—	
Sum and av. of above (no radiation)	11	979	0.997	0.003	0	—		—	
Specific control‡ 100 r of x-rays	2	200	0.78	0.14	0.085	107	68–147	99	55–141
Specific control‡ 135 r of x-rays	7	246	0.72	0.175	0.175	127	87–165	163	120–206

* None: from the plants used at the tests.
† Specific control: from plants treated exactly as for a test, but not irradiated.
‡ Specific control: from plants treated exactly as for a test, but irradiated with 100 r and 135 r of x-rays.

comparisons are independent of the actual neutron dose.[3] Both these biological effects resulting from the test neutron radiation can be expressed (by using the laboratory-derived relation of effect to x-ray dose) as "dose (r) of x-rays to produce equal effect," which is compared for mice and *Tradescantia* in Fig. 3. The curves have been displaced upward to avoid confusion with the other curves. From the line fitted to the three points it can be seen that the effect of the test neutrons, relative to x-rays, is about two times as great on *Tradescantia* as it is on mice, at least over the range of doses experienced. This figure is in fairly good agreement with what is known about the RBE of the neutrons to x-rays for the two organisms. The following *Tradescantia* experiments by Kirby-Smith and Swanson (*6*) offer a solution to the problems left unsolved by these incomplete neutron experiments.

A final instrumental calibration of *Tradescantia* was made to be sure it had not altered its response because of different conditions or the time interval between the control calibrations at Oak Ridge and the test experiments at the test site. The specific control experiments at the test site used identical methods of handling and the same plants as were used at the nuclear tests, except that no dose, or a measured dose of hard x-rays was given. The results are summarized in Table 10.

The conditions and methods of handling have not caused any spontaneous aberrations. Also, a dose of radiation at test site produced the same amount of effect as an equal dose given in Oak Ridge. This can be seen from the data, for example, where 100 r delivered at test site produces an effect (chromosome deletions and exchanges) equal to what 99 r and 107 r, respectively, caused in Oak Ridge, on the basis of the Oak Ridge control data, Table 5. The stability of *Tradescantia* for the two situations seem well established. The result is what was expected, on the basis of previous experience.

[3] The author is indebted to Robert E. Carter for allowing him to use this small bit of his much more extensive experimental data (*5*).

References

1. LEA, D. E. *Actions of Radiations on Living Cells*, Chaps. 6, 7. New York: Macmillan, 1947.
2. CATCHESIDE, D. G. In *Advances in Genetics*, pp. 271–349. New York: Academic Press, 1948.
3. MOOD, A. M. *Introduction to the Theory of Statistics*, pp. 300–301. New York: McGraw-Hill, 1950.
4. KIRBY-SMITH, J. S., and DANIELS, D. S. *Genetics* **38**, 375 (1953).
5. CARTER, R. E. *Amer. Naturalist*. In press.
6. KIRBY-SMITH, J. S., and SWANSON, C. P. *Science* **119**, 42 (1954).

Manuscript received December 14, 1953.

The Effects of Fast Neutrons from a Nuclear Detonation on Chromosome Breakage in *Tradescantia*[1]

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The work of Conger (*1*) on the effects of radiations from nuclear detonations on chromosome breakage in *Tradescantia* has shown the need for more quantitative data on the effects of fast neutrons on this material. The present investigation was thus undertaken to complement this earlier work. From these conditions, a reliable physical determination of the fast neutron dose delivered to the biological material in the field has been the major prerequisite for a successful experiment. This condition, although not complete, has been fulfilled sufficiently to justify publishing the present data. In addition to the field test results, the cyclotron calibration and control data for chromosome breakage by fast neutrons are of some interest in themselves.

Tradescantia paludosa inflorescences were exposed at the field tests in a number of the lead hemisphere neutron stations previously described in the paper by Conger (*1*). Material in seven stations received doses in the ranges suitable for studies of chromosomal breakage. Slides were prepared from the exposed anthers 24 hours and 4 days after exposure, allowing both chromatid and chromosome aberration frequencies to be determined at a number of dosage points.

These data are summarized in Tables 1 and 2. The neutron doses in rep given here are final values derived from the Sheppard-Darden ion-chamber readings (see Appendix). These figures have not been corrected for any contaminating gamma rays due to the uncertainty in this contribution. As will be seen later, this correction factor cannot be great. Rep values in parentheses have been determined from dosimeters placed in the front position in the hemispheres. Not enough physical data were obtained to derive a similar least squares fitted set of doses for the back positions. The most reliable dose-aberration frequency curves are thus obtained from measurements made at the front positions. In the hemispheres containing appreciable numbers of mice, the *Tradescantia* chromosome aberration data indicate an attenuation in neutron dose from front to back of approximately 25%. This can be clearly seen in the figures for stations 1, 2, 3, 4, and 5. In addition to the field test data, the tables contain the results of calibration studies made at Oak Ridge prior to the test. These measurements were made with a Victoreen chamber calibrated against Rossi-Failla tissue equivalent ion chambers as outlined by Sheppard and Darden (see Appendix). Plots of biological damage for chromosome and chromatid aberrations against physically determined dose for both the field test data and the cyclotron control data are shown in Figs. 1 and 2.

As has been pointed out, the major uncertainty in

[1] Work performed under Contract No. W-7405-Eng-26 for the Atomic Energy Commission.

[2] The authors acknowledge the unselfish cooperation during the detonation experiments of Harold H. Plough, at that time Assistant Chief, Biology Branch, Division of Biology and Medicine of the U. S. Atomic Energy Commission.

TABLE 1. *Tradescantia* chromosome aberrations.

Station	Dose (rep)	Cells scored	Aberrations per 100 cells	
			Deletions	Exchanges
		A. Field Test		
1 (Front)	107.7	150	217	166
(Back)		100	172	123
2 (Front)	74.3	200	140	130
(Back)		200	128	102
3 (Front)	48.6	400	94	86
(Back)		300	67	65
4 (Front)	23.2	200	33	37
(Back)		300	26	31
5 (Front)	16.4	600	22	21
(Back)	10.1	600	15	15
		B. Oak Ridge Cyclotron		
	67.5	300	122	91
	56	300	94	79.5
	45	300	72	67.5
	22.5	300	39	32.5

the physical dosage measurements is in the actual amount of contaminating gamma rays present in the lead hemispheres. Recent examination of the results of chemical dosimetry, as well as the U.S. National Bureau of Standards film pack data, indicates that, although gamma rays were undoubtedly present in the tests, the radiation did not result in a dominant contribution to the total dose. At the outer *Tradescantia* stations, we assume a 25% contribution due to gamma rays as an upper figure. Russell (*2*) has shown, for dominant lethals in mice, that if the ion-chamber measurements were correct, and if the biological efficiencies of detonation and cyclotron neutrons were the same, then the biological results observed by him would indicate a gamma contamination of 25%, with 95% confidence limits of 7.4 and 40%.

TABLE 2. *Tradescantia* chromatid aberrations.

Station	Dose (rep)	Cells scored	Aberrations per 100 cells		
			Chromatids	Isochromatids	Exchanges
		A. Field Test			
4 (Front)	15	300	109.3	160.3	80.3
5 (Front)	9	450	51.5	82.7	37.1
6 (Front)	1.3	700	10.7	11.9	3.9
		B. Oak Ridge Cyclotron			
	10.8	450	72.3	95.8	46.0
	5.4	250	37.6	40.2	17.2
	2.7	300	17.5	25.0	7.9

Considering *Tradescantia* as a biological dosimeter, the close agreement in the biological effects of cyclotron neutrons measured in rep at Oak Ridge and those due to detonation neutrons measured by ionization dosimeters in the lead hemispheres indicate that the uncertainties in the physical measurement of neutron dose in the field are considerably less than the factor of 2 conservatively set by Sheppard and Darden (see Appendix). This conclusion is based on the assumption that there is either little difference between the neutron energy spectrum within the lead hemispheres and that in the lead exposure chambers used in the cyclotron studies, or that the dependence of chromosome breakage on neutron energy over these ranges is slight. Recent studies of our cyclotron facilities and information available to us on the neutron spec-

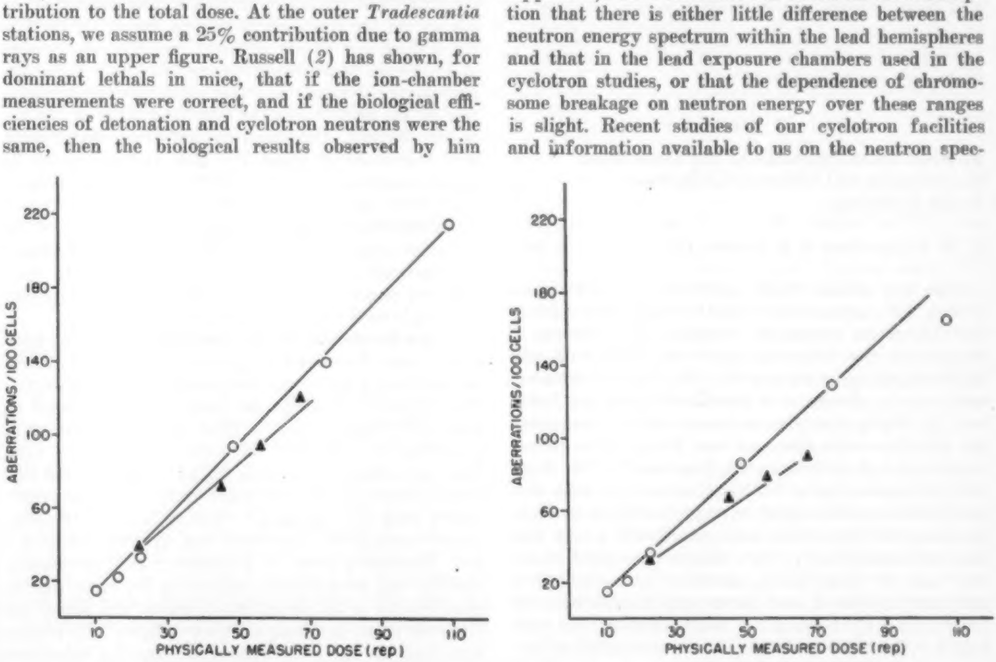

FIG. 1. (a) Chromosome deletions. ▲, Cyclotron control data. ○, Field test data. (b) Chromosome exchanges. ▲, Cyclotron control data. ○, Field test data.

trum in the lead hemispheres are in agreement with the first assumption. Although controlled laboratory experiments to determine the variation in chromosome aberration frequencies with incident neutron energy must be carried out before *Tradescantia* can function reliably as a neutron dosimeter, the present general agreement in dose determined in the field from biological and physical measurements is impressive. We can also assume that, in a general qualitative way for *Tradescantia,* there are no very great differences in the effects of laboratory-produced fast neutrons and those arising under the burst conditions of a nuclear detonation. Certainly, the relative biological efficiency (RBE) for detonation neutrons compared with fast neutrons from a cyclotron is $1 \pm 25\%$.

Comparing our cyclotron neutron data with the extensive x-ray control data obtained by Conger prior to the early tests, some fairly reliable determinations of the RBE of fast neutrons and x-rays can be made. In the case of predominantly one-hit chromatid aberrations, i.e., chromatid plus isochromatid breaks, an RBE for neutrons to 250 kvp x-rays of 13 was found. For chromatid/chromatid interchanges, as well as chromsome deletions and exchanges, in which a linear relation of aberrations with dose does not exist for x-rays, a definite exact RBE cannot be obtained. By assuming x-ray intensities sufficiently high to give maximum breakage rates and forcing the dose curves to a linear relation, an RBE of approximately 13 for chromatid/chromatid interchanges and 7 and 10 respectively for chromosome deletions and chromosome exchanges can be assigned.

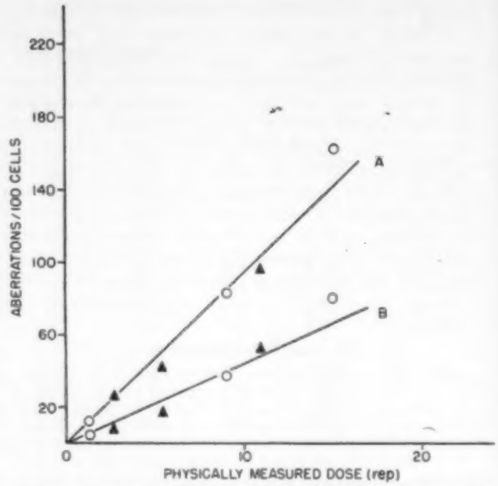

FIG. 2. Chromatid aberrations. Curve A, isochromatid breaks. Curve B, chromatid interchanges. ▲, Cyclotron control data. ○, Field test data.

APPENDIX

Physical Dose Estimates in the Detonation Experiments and Neutron Calibration in the Cyclotron

C. W. Sheppard and E. B. Darden, Jr.

The dose in the ORNL cyclotron was determined with a BF_3 proportional counter calibrated against two Victoreen condenser r-meters. The number of reps/n for the 100-r chamber with thimble of conducting lucite-graphite was 1.7. For the 25-r chamber, which was a conventional Bakelite thimble, the factor was 2.5. These figures were determined by comparing the readings with those of two Rossi-Failla tissue-equivalent ion chambers, one provided by Dr. Rossi and one constructed at ORNL. Comparisons were also made with the readings of an ethylene-filled polyethylene chamber whose walls were coated with a very thin layer of graphite (*3*). This "tissue equivalent chamber" and the Rossi-Failla chambers were themselves calibrated against x- and gamma-ray standards in the laboratory (*4*). Gamma-ray contamination was estimated with a condenser-type ion chamber made of bismuth whose design was similar to that of a beryllium chamber used by us for gamma-ray estimates in the presence of high fluxes of thermal neutrons (*5*). Slow neutrons were determined by gold activation. Approximately one gold neutron was found for every ten total neutrons. The neutrons were made by the Be^9 (p, n) reaction. The energy distribution was estimated by converting the spectrum for a thin target (*6*) to that for a thick one at our different angle of observation and different bombarding energy (22 Mev). Some approximate allowance was also made for the degradation of the neutrons in the 2-in. lead walls of the exposure facility. The result gave a broad distribution with maximum at about 1–2 Mev and tailing off at higher energies to less than 20% total neutrons above the S threshold. Because of the difficulties of physical measurements in the cyclotron, exact control of all variables was not possible and we therefore estimate the uncertainties as about $\pm 20\%$. Attempts to compare our dosimeter readings with those obtained under better physical conditions are now in progress.

In the detonation experiments, the methods of dosimetry were developed as a compromise when it was learned that a well-conceived program of tissue-equivalent chamber development could not be extended to cover our requirements. A total of 19 chambers were completed in time for the experiments. They were built according to the same design as that of the bismuth chambers, but had inner walls of polyethylene coated with thin aquadag.[3] Spacing between the concentric cylindrical electrodes was approximately 0.5 mm. Insulators were of fluorothene and mechanical rigidity was achieved by supporting the inner plastic electrode on a 2S aluminum cylinder and the outer electrode in an enclosing aluminum sleeve. The plastic was thick enough in all cases to stop the beta rays from the activation of aluminum. The chambers were

[3] We wish to acknowledge the assistance of R. K. Abele of the Oak Ridge National Laboratory, Instrumentation and Controls Division, in a portion of the design.

filled with air, relying on the closeness of the electrode spacing to obtain maximal efficiency of ion collection and minimal dependence of the reading on the energy of the neutrons. The sensitivity of a chamber depends on its collecting volume and the latter was varied somewhat by filling a variable amount of air space with insulation. In this way, readings on scale were achieved at almost all of the stations where instruments were placed. Investigation of the calibrations indicated that individual instruments varied considerably but, due to the large number of chambers and the use of statistical methods, the aggregate effect of the individual fluctuations was small. Because lowering the sensitivity by closer electrode spacing introduces serious problems, such as the need for polishing the plastic to a mirror finish, and the electrical difficulties produced by small amounts of particulate matter in the chambers, the highest dose that could be read was about 250 rep. The chambers were calibrated in the cyclotron facility. Because of their design, moderate variations in the neutron spectrum should not affect the calibration. This was tested by introducing paraffin into the neutron beam, with little effect on the calibration factors. In spite of the high voltage gradient on the insulators, leakage was not a serious problem. Soakage of the insulators presented no serious difficulty.

Gamma-ray contamination in several stations was estimated in one detonation experiment by the use of nine chambers in which the collecting electrodes were made of lead. Unfortunately, the accuracy of this method decreases rapidly as the gamma-ray component increases. Lead-lined chambers are quality dependent and the gamma-ray spectrum was not known. The calibration of the chambers against Co^{60} gamma rays was the method of choice. Some confidence can be placed in the allowance for effects which would make the observed neutron dose spuriously high. Effects which would make the readings too low cannot be as easily evaluated. In addition to these difficulties, there is some evidence that the instruments are partially sensitive to slow neutrons even though particular effort was made in the design to minimize this. In general, the readings indicated a considerable gamma ray contamination. The neutron component of the dose recorded by the polyethylene chambers is probably low, because there is some evidence that their ion collection is impaired by the glutting effect of the high momentary ionization density. Since the duration of the exposure was short, the intensity was correspondingly high. Taking all these complicating effects into account, we feel that it is highly unlikely that the ion chambers have overestimated the dose. They may conceivably have underestimated it but not by more than a factor of 2. It is not impossible that they were more accurate than we have supposed. It is anticipated that, as a result of present efforts to refine physical dosimetry of neutrons, future work will be on a much sounder basis.

References

1. CONGER, A. D. *Science* **119**, 36 (1954).
2. RUSSELL, W. L. Private communication.
3. DAINTY, J. Can. Natl. Res. Council Unclassified Rept. CRM-482, Chalk River (1950).
4. DARDEN, E. B., JR., and SHEPPARD, C. W. USAEC Unclassified Rept. ORNL-1002, Office of Tech. Serv., Washington, D. C. (1951).
5. DARDEN, E. B., JR., SHEPPARD, C. W., and EMERSON, L. C. *Rev. Sci. Inst.* **23**, 568 (1952).
6. GUGELOT, P. C. *Phys. Rev.* **81**, 51 (1951).

Manuscript received December 14, 1953.

An Interesting Phenomenon Associated with Irradiation of Dry Maize Seeds[1]

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In the course of experiments conducted to determine the effect of neutron radiation from a nuclear detonation on dry maize seeds, an interesting and completely unexpected phenomenon was observed at the high-dosage levels. This phenomenon is of purely biological interest but serves to emphasize that in the field of biological dosimetry extreme care must be taken to avoid the use of complex biological effects such as growth and survival, which involve a large number of little understood physiological reactions. The observed phenomenon was simply that within a certain dose range there was an unexpected relation between dose and seedling height.

Dry corn seeds were exposed in 7-in.-thick lead hemispheres to the radiation produced by a nuclear detonation. The lead hemispheres were designed to shield the material from the gamma rays so that, in the main, only the effects of fast neutron bombardment were studied. The hemispheres also protected the seeds from temperature and shock effects. One hundred seeds were placed in each hemisphere about 9 hours prior to and recovered approximately 3 hours after the detonation. The recovered seeds were treated with a dust disinfectant, and planted in sand. Ten days after planting the seedlings were removed from the seedling bed and scored. Both the percentage of seeds which germinated and the seedling height were recorded. Germination was found to be unaffected by the radiation. Every lot of treated seeds showed over 90% germination.

The results on seedling height are shown in Fig. 1. Proceeding from the low to the high doses, the seedlings show an initial decrease in height followed by an increase as the high dose levels are approached. There are two possible conclusions which could be drawn

[1] Work performed under Contract No. W-7405-Eng-26 for the Atomic Energy Commission.

[2] The author acknowledges the unselfish cooperation, during the detonation experiments, of Harold H. Plough, at that time Assistant Chief, Biology Branch, Division of Biology and Medicine of the U.S. Atomic Energy Commission.

FIG. 1. Relation between seedling height and neutron dose (rep) from nuclear device test. Confidence limits are 95%.

from these data. The first is that there is a direct correlation between seedling height and neutron dose, signifying a very large error in the physical dose estimates. This would indeed be a surprising result since it would mean that the material exposed in hemispheres close to the detonation received a lower dose of radiation than did the material in the more distant hemispheres. The dosage was estimated by an extrapolation of the rep at the low dose ranges as measured by the polyethylene thimble chambers of C. W. Sheppard. The extrapolation was made to follow the slope of the sulfur neutron flux. The second possibility is that the admittedly rough physical dose estimates were not very seriously in error, thus pointing to a failure of correlation between seedling height and dose.

To distinguish between these two alternatives, similar experiments were conducted using gamma radiation from a Co^{60} source where the dose can be measured more accurately. Seeds were exposed to doses of radiation ranging from 75,000 to 500,000 r. The same phenomenon was observed in these experiments (Fig. 2). There is an increase in seedling height with increased doses above 125,000 r with the effect leveling off at 400,000 r.

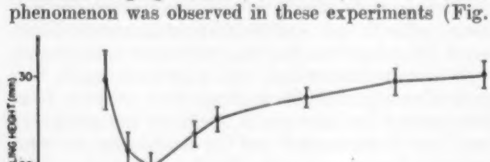

FIG. 2. Relation between seedling height and γ dose from Co^{60} source. Confidence limits are 95%.

Do these data point to a stimulatory effect of radiation on plant growth? The answer is definitely, no! Cytological examination of the root tips from plants which received high doses of radiation revealed a complete absence of cell division. In other words, the "growth" was due entirely to cell elongation in these seedlings. This was borne out by the observation that seedlings which received more than 9000 rep at the test and 125,000 r of gamma radiation from the cobalt source reached their maximum height at about 5 days after planting. No further elongation was observed for the next 5 days. The seedlings irradiated at the higher dose levels were not only taller but also much healthier in appearance than those at the lower levels. In fact, those seedlings could not be differentiated from normal unirradiated young seedlings except that there was a cessation of further growth after approximately 5 days.

The conclusion drawn from these data is that at high radiation levels the seeds are killed in the sense that no further cell divisions occur. To explain the increased "growth" made by the seedlings which received the higher doses it is postulated that the effect was due to an inactivation by high doses of radiation of those processes in the cell which are responsible for the breakdown of the plant tissue, probably the enzyme systems. Thus in the neighborhood of 125,000 r cell division is completely knocked out and the plant tissue degenerates. At higher doses both cell division and enzymatic activity are affected so that the seedling grows to its maximum height through cell elongation and for a period remains at a status quo, neither degenerating nor making more growth.

Manuscript received December 14, 1953.

The Production of Dominant Lethals in *Drosophila* by Fast Neutrons from Cyclotron Irradiation and Nuclear Detonations[1]

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A considerable area of disagreement exists between the relative biological effectiveness (RBE) of x-rays and fast neutrons in producing chromosome aberrations in plants and in *Drosophila*. For example, Thoday (*1*) reports that in *Tradescantia* fast neutrons are 5–10 times as effective per unit dose in producing interchanges and 3.6 and 2.4 times as effective in in-

[1] Work performed under Contract No. W7405-Eng-26 for the Atomic Energy Commission.

[2] The authors would like to acknowledge the unselfish cooperation, during the detonation experiments, of Harold H. Plough, at that time Assistant Chief, Biology Branch, Division of Biology and Medicine of the U.S. Atomic Energy Commission.

TABLE 1. The induction of dominant lethals by fast neutrons.

Cyclotron			Nuclear device A			Nuclear device B		
Dose (rep)	Eggs counted	Hatch freq.*	Dose (rep)	Eggs counted	Hatch freq.*	Dose (rep)	Eggs counted	Hatch freq.*
None	3889	0.968	None	1807	0.978	None	2584	0.946
250	2867	0.673	129	3428	0.853	32	2318	0.978
500	1754	0.469	340	3325	0.670	65	2333	0.941
700	3494	0.324	1250	2660	0.225	140	1982	0.756
1000	2193	0.275	2400	4687	0.0406	400	2663	0.574
1650	3524	0.0721	3300	1806	0.0204	740	2438	0.344
2700	3140	0.0125	5300	1859	0.00110	2050	2575	0.0632
3500	1007	0.00205						

* In the irradiated series, the actual hatch frequency has been divided by the control frequency. Thus the former frequency is related to a control value of 1.0.

ducing isochromatid and chromatid breaks, respectively. On the other hand, Demerec *et al.* (*2*), studying cytologically recoverable rearrangements in *Drosophila melanogaster* salivary glands, Eberhardt (*3*), working with induced position effect at the *ci* locus, and Catsch *et al.* (*4*), determining the frequency of translocations between chromosomes 2 and 3, find that fast neutrons are no more effective than x-rays. The published results on dominant lethals in *Drosophila* (most of which are undoubtedly caused by lethal chromosomal aberrations) confuse the picture even more. In this case, fast neutrons are shown to be more effective, but the RBE's are only as great as 1.5 (*5*) or 2.0 (*6*).

The question posed by these conflicting results is whether the reported difference in the comparative behavior of *Tradescantia* and *Drosophila* chromosomes to neutron and x-irradiations is real, or whether the discrepancy is an artifact caused by either inaccurate neutron dosimetry or use of neutron sources contaminated with unknown amounts of gamma radiation, or both. It is a well-known fact that even at the present time the dosage (rep) of fast neutrons cannot be measured with the desired precision (i.e., ±5% or better), especially when there is gamma-ray or slow neutron contamination, as is almost always the case. However, the dosimetry problem is much nearer solution at the present time than it was when the above-mentioned *Drosophila* work was performed. Therefore, we feel that our finding—that the RBE for dominant lethals in *Drosophila melanogaster* is in the same range as that for chromosome rearrangements in *Tradescantia*—is the result of the improvements which have been made in neutron irradiation methods and dosimetry within the past few years.[3]

The Oak Ridge 86-in. cyclotron was used as the source of neutrons in the laboratory experiments (*7*). A description of the lead-lined facility in which the flies were exposed and the method of neutron dosimetry used are given in (*8*). It should be noted, however, that several calibration runs were made with the 100-r-7 thimble chamber just prior to exposure of the flies. Oregon-R males of from two to four days of age were placed in lusteroid tubes which were inserted into the facility at the spot where dosimetry measurements had been made. After exposure, the males were mated to Oregon-R females and the exact procedure given by Baker and Von Halle (*9*) was used in collecting the eggs and determining their survival frequency.

The results of the cyclotron treatment are presented in Table 1. Contrary to the finding in x-ray-induced dominant lethals (*9*), there is no difference in the hatch frequency among eggs fertilized by the first and second batches of sperm. Consequently, the data from the two sperm batches are combined in this table.

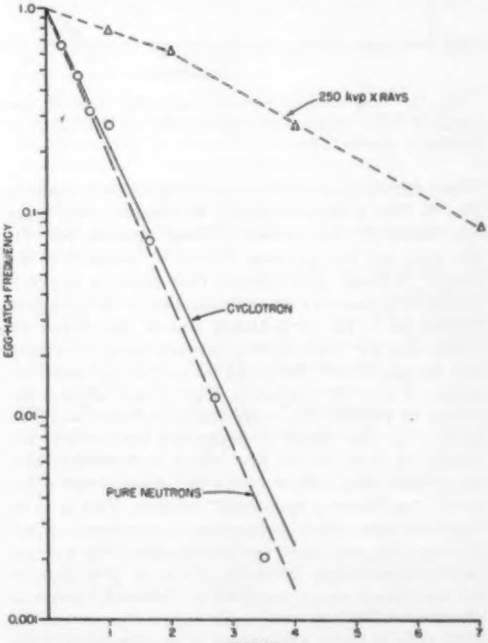

FIG. 1. The relation between dose of fast neutrons from the cyclotron and the frequency of dominant lethals induced.

[3] The authors are indebted to C. W. Sheppard and E. B. Darden for calibration of the neutron facility in the cyclotron and for dosage measurements at the field tests. Without these measurements our results would be meaningless.

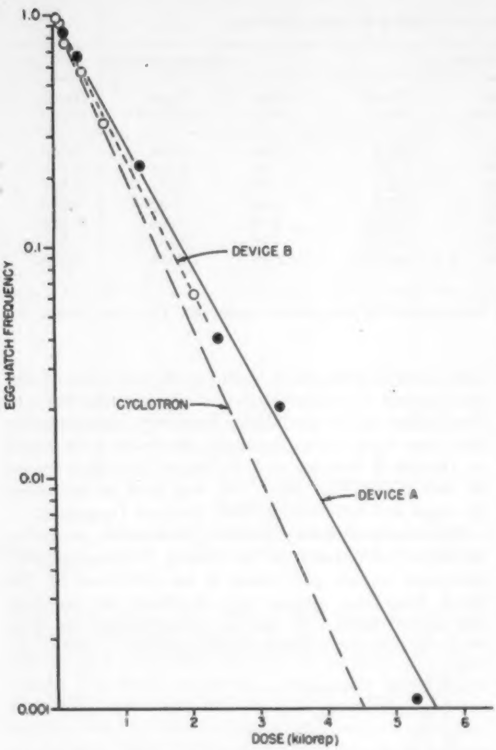

FIG. 2. The relation between estimated dose of fast neutrons from nuclear detonations and the frequency of dominant lethals induced.

These data are plotted on a semilogarithmic scale in Fig. 1. The weighted (np/q) exponential regression line which, by the method of least squares, best fits the data has the equation $\hat{Y}=e^{1.52D}$, where D is the dose in kilorep. It is known that there is approximately 10% gamma-ray contamination in the cyclotron facility used. The long-dashed line in this figure indicates the expected relation between hatch frequency and dosage if there had been no gamma-ray contamination $\hat{Y}=e^{-1.66D}$). Also in Fig. 1 are plotted the results of the 250-kvp x-ray study of Baker and Von Halle (*9*). This figure presents two facts which are worthy of note. In the first place, it is evident that the neutron data follow a "one-hit" curve whereas the x-ray data follow a "multi-hit" relation. This is to be expected since lethal chromosomal aberrations caused by more than one break could be produced by a single recoil proton track. Secondly, it can be seen that, in the low dosage range, neutrons are about 7.3 times as effective as 250-kvp x-rays. At higher dose levels, the RBE falls to about 4.8 because of the change in slope of the x-ray curve.

Since the cyclotron results appeared to rest on as good physical measurements as are presently available, it was felt that determination of the dominant lethal frequency induced by neutrons from nuclear detonations might be of some theoretical and practical interest. Of primary theoretical interest is the fact that neutrons from nuclear detonations are all delivered within a matter of microseconds, while cyclotron neutrons were given in a matter of minutes. Naturally, the feasibility of such an intensity study would depend on whether an accurate measurement could be made of total dosage of a magnitude that would be useful in *Drosophila* experiments. Unfortunately, no physical dosimeters which could measure dosage in the 500-rep region and above were available in the field-test experiments to be described. Therefore, one is left with the alternative of considering the dominant lethal frequency as a biological dosimeter in this dosage range. The usefulness of this alternative rests on several unproven assumptions, among which are the assumptions that the great intensity difference and any dissimilarity in the energy spectrum of neutrons from the detonations and cyclotron are without influence on the dominant lethal frequency.

With these thoughts in mind, flies were exposed to neutrons from nuclear detonations by placing them within the lead hemispheres described by Conger (*10*). Hemispheres were located at various distances from ground zero in order that exposure to different dosages could be made.[4] As previously noted, there were no physical dosimeters in the range where most of the *Drosophila* were placed although the flux of sulfur neutrons (3 Mev and above) were available. Nevertheless, polyethylene thimble chambers of C. W. Sheppard (*8*) were in hemispheres at lower dosage levels. The rep measurements of these thimble chambers did parallel quite closely the sulfur neutron flux in this region. In order to obtain an estimate of the dosage in the hemispheres where *Drosophila* were placed, the thimble chamber readings were extrapolated into this region by having them continue to parallel the sulfur neutron flux. The dosages given in Table 1 and Fig. 2 were determined in this manner.

Only slight differences existed between the experimental techniques of the field-test experiments and the cyclotron and x-ray studies. The males were not mated until approximately 4 hours after the detonation. Also, the first 24-hour mating period of the males was done under field, rather than laboratory, conditions.

The data obtained from two nuclear detonations are shown in Table 1 and Fig. 2. In spite of the rather crude method of estimating dosage, it is comforting to note that in both tests the points fall quite close to a straight line passing through at 1.0 at zero dosage. The weighted regression lines for device A and B respectively are $\hat{Y}_A=e^{-1.24D}$ and $\hat{Y}_B=e^{-1.36D}$. In a comparison of results from field tests and the cyclotron irradiations it appears that more eggs hatch per unit dose in the former experiments. The question arises as to whether this discrepancy is due to the lower effectiveness of neutrons from nuclear detonations than those

[4] The invaluable advice and assistance given by Robert E. Carter during the field tests are deeply appreciated.

produced by the cyclotron, or to overestimation of the neutron dose in the field experiments. A satisfactory answer to this question cannot be given on the basis of these experiments. It is known that gamma-ray contamination existed within the hemispheres and that the amount of contamination varied with the hemispheres. It does not seem likely that this can explain the difference since experiments conducted in the same hemispheres with another genetic effect (sex-linked recessive lethals) having a low RBE, and thus more sensitive to gamma-ray contamination, gave no evidence of any larger contamination than in the cyclotron (*11*). The final answer to this question will have to await the development of reliable neutron dosimeters of sufficient capacity.

Until adequate dosimeters are available, the frequency of dominant lethals may be useful in nuclear detonations as a rather rapid, but crude, biological measurement of fast neutron dosage at high levels. For example, it may be determined from Table 1 that with device A the biological dose was within about 23%, and with device B within approximately 12%, of the dose extrapolated from physical instruments.

In summary, the main conclusion to be drawn from the data presented is that the relative biological effectiveness, in producing chromosome aberrations, of fast neutrons (as compared with x-rays) is about as great in *Drosophila* as in *Tradescantia*.

References

1. THODAY, J. M., and LEA, D. E. *J. Genetics* **43**, 189 (1942).
2. DEMEREC, M., KAUFMANN, B. P., and SUTTON, E. *Genetics* **27**, 140 (1942).
3. EBERHARDT, K. *Naturwissenschaften* **31**, 23 (1943).
4. CATSCH, A., PETER, O., and WELT, P. *Ibid.* **32**, 230 (1944).
5. DEMPSTER, E. R. *Proc. Natl. Acad. Sci.* **27**, 249 (1941).
6. FANO, U. *Genetics* **29**, 361 (1944).
7. LIVINGSTON, R. S. *Nature* **170**, 221 (1952).
8. KIRBY-SMITH, J. S., and SWANSON, C. P. *Science* **119**, 36 (1954).
9. BAKER, W. K., and VON HALLE, E. *Proc. Natl. Acad. Sci.* **39**, 152 (1953).
10. CONGER, A. D. *Science* **119**, 36 (1954).
11. MICKEY, G. H., and YANDERS, A. F. Unpublished.

Manuscript received December 14, 1953.

The three papers by J. S. Kirby-Smith and C. P. Swanson, Drew Schwartz, and W. K. Baker and E. Von Halle were part of a larger test program on the genetical effects of radiation from nuclear detonations conducted under AEC direction. Additional papers will appear in the literature.

Comments and Communications

Nomenclature of Cyclohexane Bonds

IT was shown originally by x-ray and electron diffraction, and has been confirmed by other physical and by chemical means, that the most stable and permanent form of the cyclohexane ring is that particular strainless form which is sometimes likened to a chair or a staircase. Geometrically, its chief feature is a sixfold alternating axis of symmetry. Its 12 extracyclic bonds fall into two classes (*1*): 6 lie parallel to the axis, while 6 extend radially outward at angles of $\pm 109.5°$ to the axis. The stereochemical properties of substituents bound by these two classes of bond are so different that a need has been felt for verbal and symbolic means of distinguishing the classes.

The first suggestion (*2*) to this end designated the six parallel bonds as 'ϵ' and the others as 'κ'. However, although these symbols have been considerably used, their origins in the Greek language, and particularly their allocation between two classes of bond, have been found difficult to remember. A more obvious description was given (*3*) when the six parallel bonds were called "polar" and the others "equatorial" in analogy to the geographical terms. This nomenclature has had a wide use, but is unsatisfactory in that it employs the word "polar" for a stereochemical concept, thereby tending to confuse discussions which have to take account of the electropolar nature, side by side with the stereochemical character of cyclohexane substituents.

The purpose of this note is to suggest a simple change which avoids these difficulties. It is that the six bonds parallel to the main cyclohexane axis should be called "axial"[1] (and symbolized '*a*'), while the other six retain the name "equatorial" (and become symbolized '*e*'). The private discussions we have had with friends and colleagues lead us to hope that this suggestion may find favor.

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References

1. KOHLRAUSCH, K. W. F., REITZ, A. W., and STOCKMAIR, W. *Z. physik. Chem.* **B32**, 229 (1936).
2. HASSEL, O. *Tidsskr. Kjemi, Bergvesen Met.* **3**, 32 (1943).
3. BECKETT, C. W., PITZER, K. S., and SPITZER, R. *J. Am. Chem. Soc.* **69**, 2488 (1947).

[1] The term "axial" was suggested to us by Professor C. K. Ingold, London.

Received December 7, 1953.

Book Reviews

Energy in the Future. Palmer Cosslett Putnam. New York: Van Nostrand, 1953. 556 pp. Illus. + tables. $12.50.

The book, *Energy in the Future,* is the product of a study made by the author for the Atomic Energy Commission. The author was requested to make a background study for the "Commission's consideration of the economic and public policy problems related to the development and use of machines for deriving electrical power from nuclear fuels." The author states his purpose as providing "the Atomic Energy Commission with the first comprehensive but rough analysis of the maximum plausible market for nuclear fuels."

In order to attack this problem, a rather extensive survey was made of the literature dealing with world populations and population trends, past and present patterns of various kinds of energy consumption, and a review of recoverable reserves of fossil fuels. This assembly of information relative to future world energy needs is one of the chief contributions the book has to make.

The author places himself in the role of an imaginary trustee of the world's energy, who, writing with very broad strokes, analyzes the maximum plausible populations in the years A.D. 1950 to 2050, the maximum plausible quantity of energy in demand for this period, the minimum plausible rate of growth of efficiency of conversion of energy, and the maximum plausible role of nuclear fuels.

Cautioning throughout the book that many speculations have been made to establish an order of magnitude and provoke discussion, the author suggests a hypothetical energy system of A.D. 2050 using nuclear fuels to supply sixty percent, residual fossil fuels twenty-five percent, and income energy, including solar, tidal, wind and wood fuels, as fifteen percent of the total energy output to the system.

The very large amount of solar energy falling on the earth is reported by the author. He points out, for example, that the energy released by an atomic bomb is roughly equal to the energy in the sunlight falling on the area of destruction during one sunny day. The author does not give clear reasons, however, for his stronger reliance on nuclear power for the future. Perhaps a report written for a solar energy commission would have more optimism for this source of energy.

The ten chapters take up about one-half of the total number of pages of the book. The remainder is the appendix, giving extensive notes on various chapters. An indication of the very extensive survey of the literature forming the backbone of the book is given by the very valuable fifty pages of bibliography, 160 figures, and 152 tables. Industry, government, and private foundations, such as Resources for the Future, Inc., are showing an increasing interest in the problems attacked in the book. A report from the "Mid-Century Conference on Resources for the Future," held early in December 1953, unfortunately was not available for comparison at the time of this review.

The author is deadly serious throughout his study of the energy demands for the future, but for one exception. The only picture of a human in the book is that of a very charming young Iranian girl, who, with a quiet philosophical smile, is cooking the family meal of vegetable stew in a pot over a fire of straw and cow dung.

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New Books

Atoms and Energy. H. S. W. Massey. London: Elek Books; New York: British Book Centre, 1953. 174 pp. Illus. $3.50.

German Readings in Science: For intermediate students. Nelson Van de Luyster. New York: American Book, 1953. 280 pp. Illus. $2.85.

The Limits of the Earth. Fairfield Osborn. Boston: Little, Brown, 1953. 238 pp. $3.50.

Chemie Lexikon, Vols. I and II. 3rd ed. Hermann Römpp. Stuttgart: Franckh'sche Verlag, 1952–53. 2108 pp. Illus. Clothbound, DM 84 a vol.

A List of the Names Proposed for Genera and Subgenera of Recent Mammals. From the publication of T. S. Palmer's *Index Generum Mammalium,* 1904 to the end of 1951. L. R. Conisbee. London: British Museum (Natural History), 1953. 109 pp. 1 £.

Laboratory Manual for General Botany. Ward L. Miller. Minneapolis, Minn.: Burgess, 1953. 133 pp. $2.50.

Method and Theory in Experimental Psychology. Charles E. Osgood. New York: Oxford Univ. Press, 1953. 800 pp. Illus. $10.00.

A Refresher Course in Mathematics. F. J. Camm. New York: Emerson, 1953. 240 pp. Illus. $2.95.

Textbook of Genetics. William Hovanitz. Houston–Amsterdam: Elsevier, 1953. 419 pp. Illus. $5.95.

Applied Electron Microscopy. Robert B. Fischer. Bloomington, Ind.: Indiana Univ. Press, 1953. 231 pp. Illus. $4.85.

Flora of West Virginia, Part II. P. D. Strausbaugh and Earl L. Core. Morgantown, W. Va.: Bookstore, West Virginia Univ., 1953. 570 pp. Illus. $1.00.

Elementary Mathematics from an Advanced Standpoint; Vol. I: ***Arithmetic, Algebra, Analysis.*** Felix Klein. Trans. from 3rd German ed. by E. R. Hedrick and C. A. Noble. New York: Dover, 1953. 274 pp. Illus. $3.25; paper, $1.50.

Oil in the Soviet Union: History, Geography, Problems. Heinrich Hassmann. Trans. with additional information from *Erdöl in der Sowejetunion* by Alfred M. Leeston. Princeton, N. J.: Princeton Univ. Press, 1953. 173 pp. Illus. $3.75.

Experimental Nuclear Physics, Vol. II. E. Segrè, Ed. New York: Wiley; London: Chapman & Hall, 1953. 600 pp. Illus. $12.00.

Nuclear Power—Its Future

ONE of the more encouraging aspects in what is, to many, a disappointingly slow approach to the utilization of nuclear energy for peaceful purposes, is the fact that the pattern is beginning to show a very real parallelism with other major technologic developments of the past. Recognition of ultimate possibilities, isolation of immediate critical problems, and an understanding of the physical phenomena basic to a solution of these critical problems are steps through which developments from the steam engine to television have all progressed. It is now beginning to be clear that the peacetime use of nuclear power will be no exception.

Papers such as those appearing in the present issue of SCIENCE show again the essential elements of this pattern. Research reactors, especially those in university installations, are destined to pay big dividends, for they contribute to each of the several stages of a major development. Such reactors of course provide facilities for the solution of research problems. But they also serve for the training of students, for gaining experience in reactor operation, and for developing self-confidence in the operating staffs. Moreover, the fact that they are usually accessible to public view and that the results obtained with them are published widely go a long way toward removing the atmosphere of mystery and awe that surrounds things atomic in the lay mind—one of the major handicaps to normal and rational technologic progress in this field.

Recent successes with reactors, including those abroad, now practically assure that at sometime in the not too distant future, nuclear power will be utilized in successful competition with power from fossil fuels. The question is no longer whether, but *when*, such utilization will begin. All this suggests the timeliness of a group of technical articles for the nonspecialist, describing the tools, the problems, and the progress of research in this fascinating but controversial field.

L. R. HAFSTAD

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More Important Than War

ONE day during the First World War the celebrated British physicist Rutherford wrote an apology for not attending a meeting that had been called to discuss a war research problem. He stated that he was too busy with experiments in which he seemed to have split the atom. "If this is true," he wrote, "it is far more important than your War."

In talking . . . about the future development of atomic energy I would like to borrow some of Rutherford's perspective. In the midst of a great war this eminent scientist glimpsed the real proportions of that force for human peace and welfare that lies in the energy from the atom—"Far more important than your War." In that thought I find a strong note of hope, and hope is the virtue in which our national stockpiles are today so low. I trust that our world will put this evaluation "Far more important than War" on the future use of atomic energy.

Such an evaluation will, I believe, come as a part of a growing awareness that atomic war because of its overdestructiveness will no longer be a useful means for solving international disputes.

Thomas E. Murray, Atomic Energy Commission, on the Electric Companies Public Information Program, Chicago, October 22, 1953.

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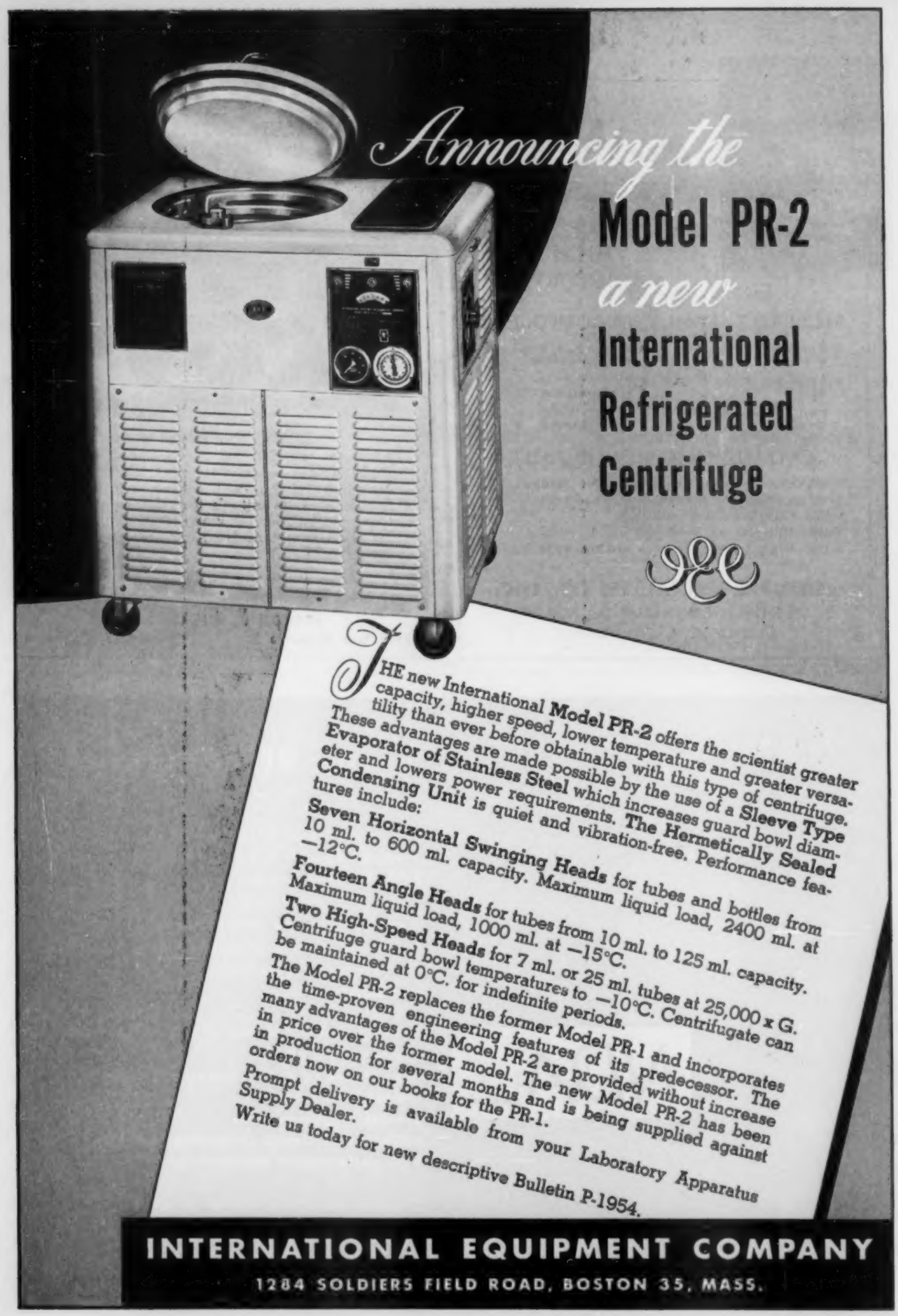
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Meetings & Conferences

January

18–23. Pakistan Science Cong., 6th annual, Karachi. (Dr. Karimullah, Deputy Director of Industries, Punjab, Lahore, Pakistan.)

19–22. American Inst. of Electrical Engineers, winter general, New York City. (H. H. Henline, 33 W. 39 St., New York 18.)

22. Public Health Workshop on Dental Care in Industry, 2nd, New York City. (A. J. Asgis, 7 E. 42 St., New York 17.)

23–28. American Meteorological Soc., New York City. (K. C. Spengler, 3 Joy St., Boston 8, Mass.)

25–27. American Soc. of Heating and Ventilating Engineers, 60th annual, Houston, Tex. (A. V. Hutchinson, 62 Worth St., New York 13.)

25–27. Conf. on High Energy Nuclear Physics, 4th annual, Rochester, N.Y. (R. E. Marshak, Dept. of Physics, Univ. of Rochester.)

25–29. Inst. of the Aeronautical Sciences, annual, New York City. (S. P. Johnston, 2 E. 64 St., New York 21.)

28. American Federation for Clinical Research, annual, Portland, Ore. (I. S. Edelman, San Francisco Hospital, San Francisco 10, Calif.)

28–30. American Physical Soc., New York City. (K. K. Darrow, Columbia Univ., New York 21.)

28–30. American Assoc. of Physics Teachers, New York City. (R. F. Paton, Univ. of Illinois, Urbana.)

28–30. High Speed Computer Conf., Baton Rouge, La. (L. Megginson, Louisiana State Univ., Baton Rouge.)

29–30. American Geophysical Union, Los Angeles, Calif. (J. P. Marble, 3221 Macomb St., NW, Washington, 8, D.C.)

29–30. Conf. on Protein Metabolism, 10th, New Brunswick, N.J. (W. H. Cole, Rutgers Univ., New Brunswick.)

29–30. Western Soc. for Clinical Research, 7th annual, Portland, Ore. (H. N. Hultgren, Stanford Hospital, San Francisco 15, Calif.)

February

1–5. American Soc. for Testing Materials, Spring, Washington, D.C. (R. J. Painter, 1916 Race St., Philadelphia 3, Pa.)

4. Instrument Soc. of America, Regional Conference, 9th annual, New York City. (L. Butzman, 103 Park Ave., New York, N.Y.

4–6. American Soc. for Quality Control, Textile Quality Control Conf., 4th annual, Raleigh, N.C. (D. Shainin, 70 E. 45 St., New York, N.Y.)

4–6. Inst. of Radio Engineers Conf. and Electronic Show, Tulsa, Okla. (D. R. Davis, P.O. Box 7221, Tulsa.)

5–6. Chicago Ophthalmology Soc., annual clinical, Chicago, Ill. (F. W. Newell, 950 E. 59 St., Chicago 37.)

7. Assoc. for Research in Ophthalmology, Midwest Section annual, Chicago, Ill. (F. W. Newell, 950 E. 59 St., Chicago 37.)

8–9. Conf. on Marine Corrosion Problems, Berkeley, Calif. (Dept. of Conferences and Special Activities, Univ. of California, Berkeley.)

13–14. American Educational Research Assoc., Atlantic City, N.J. (F. W. Hubbard, 1201 16 St., NW, Washington, D.C.)

14–16. National Soc. of College Teachers of Education, Atlantic City, N.J. (C. E. Eggertsen, School of Education, Univ. of Michigan, Ann Arbor.)

PERSONNEL PLACEMENT

POSITIONS WANTED

Entomologist, Ph.D., 4 years research, 2 years teaching. Now with Research Station. Desires teaching and/or research position. Box 2, SCIENCE. X

German Scientist, pathologist, M.D.; 32, married, child; 5 years university, experienced research worker; biophysics, optical micromethods, proteins, inflammation, cancer research; able writer, numerous publications, teaching experience; desires full time research position. Box 3, SCIENCE. X

Parasitologist: Ph.D. zoology; minor biochemistry; 6 years research assistant, medical; one year research associate, tropical, presently chief parasitologist, major pharmaceutical company, desires same or research associate, industrial, university, research, any locality. Science Division, Woodward Medical Bureau, 185 North Wabash, Chicago. X

Physical Chemist, Ph.D. Desires position medical research, pharmaceutical, electrochemical industry. 5 years professor. Research, consultant, electrochemistry, biophysics. Publications. Box 1, SCIENCE. 1/8

Pharmacologist; Ph.D.; nine years' teaching and research, small university; three years, director, pharmacological research, state laboratory. Science Division, Medical Bureau (Burneice Larson, Director) Palmolive Building, Chicago. X

POSITIONS OPEN

Biochemist: Ph.D., M.S., supervise chemistry department, 300 bed hospital university city, East. Science Division, Woodward Medical Bureau, 185 North Wabash, Chicago. X

Chemistry Department Head. Small, eastern Protestant college has retirement-caused opening in three-man department. Ph.D., age 40–45, man preferred. Undergraduate teaching only; no summer session. Box 4, SCIENCE. X

Chemist–Librarian. Wanted, to assume responsibility for smooth functioning of 20,000 volume research library and to edit weekly abstract bulletin. Scientific background and library administrative experience are required. Send personal resume to Dr. A. C. Moore, Research Dept., Parke, Davis and Co., P. O. Box 118, R. P. Annex, Detroit 32, Michigan. 12/4, 18; 1/1, 15, 29

The University of Liverpool. Applications are invited for I.C.I. Research Fellowships in Physics, Chemistry, Engineering, Metallurgy, and Pharmacology, or any related subject, to which some appointments may be made during the current academic year. The appointments will date from 1 October, 1954 (or earlier in the case of selected candidates who may be available before that date). The salary will depend upon qualifications and experience, but will normally be within the range £600–£900 per annum, together with F.S.S.U. benefits and family allowances. Applications (three copies), with a list of publications and the names of two referees, should be received not later than 1st. March, 1954, by the undersigned, from whom further particulars may be obtained. (Candidates overseas, who find it more convenient to do so, may send one copy only by air-mail.) Stanley Dumbell, Registrar. X

POSITIONS OPEN

(a) **Physician** to serve as associate director of research; preferably one interested in field of nutrition and teaching. (b) **Pharmacologist** experienced pharmacological investigation; pharmaceutical laboratories; Midwest. (c) **Physicist** particularly interested in radiation therapy dosage; department of radiology, 700-bed teaching hospital. (d) **Associate professor**, physiology; experience in teaching mammalian physiology desirable; university medical school. (e) **Psychologist**, Ph.D., for psychological testing, capable of developing training program for psychology interms; private institution, university medical center. (f) **Bacteriologist–biochemist**, qualified to do 17-ketosteroids, other advanced work; 300-bed general hospital; resort city, Southwest. (g) **Clinical biochemist**; Ph.D., qualified take charge division; fairly large hospital; $6000. S1-1 Science Division, Medical Bureau (Burneice Larson, Director) Palmolive Building, Chicago. X

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